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# SOVIET SPACE PROGRAMS: 1981–87

## PILOTED SPACE ACTIVITIES, LAUNCH VEHICLES, LAUNCH SITES, AND TRACKING SUPPORT

PREPARED AT THE REQUEST OF

Hon. ERNEST F. HOLLINGS, *Chairman*

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

Part 1

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## LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
*Washington, DC, May 17, 1988.*

DEAR COLLEAGUE: The Committee on Commerce, Science, and Transportation and the Subcommittee on Science, Technology and Space are pleased to submit Part I of a two-part report on Soviet space activities. Part I covers manned activities (including space life sciences), launch vehicles and facilities, and tracking systems.

Part II of this report, dealing with the unmanned space activities and the underlying Soviet policy regarding space, will be released later this year.

The U.S. space program is at a critical juncture and it is important for all Members of Congress, and the American public therefore, to fully understand the breadth and capability of our foreign competition, in particular the Soviet Union. To assist Members in this process, several Members of this Committee requested the Congressional Research Service to prepare an updated version of its Soviet space activities report on launch vehicle development, manned space activities, military satellites and space science.

We hope this report by the Congressional Research Service furthers public knowledge on this issue and makes people aware of the challenges that lie ahead in space. We also hope this report broadens the base of support for the U.S. space program and helps this Nation recommit itself to maintaining leadership in space.

Sincerely,

ERNEST F. HOLLINGS, *Chairman.*

# LETTER OF SUBMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
*Washington, DC, February 10, 1988.*

Senator ERNEST F. HOLLINGS,
Senator DONALD W. RIEGLE, Jr.,
Senator JOHN C. DANFORTH,
Senator LARRY PRESSLER,
*U.S. Senate, Committee on Commerce, Science, and Transportation, Washington, DC.*

DEAR SENATORS: In accordance with your request of July 23, 1987, attached is Volume 1 of *Soviet Space Programs: 1981–1987.* This report is an update of the *Soviet Space Programs: 1976–1980* series your Committee published in three volumes in 1982, 1984 and 1985. As we agreed, detailed historical information has not been included in this new volume in order to streamline the report. While a brief historical summary is provided for convenience, the majority of the text focusses only on new material. For Part I (piloted space activities), this is the years 1983–1987; for Part II (launch vehicles, launch sites and tracking support), it is the years 1980–1987. Volume 2 of the report, covering automated space missions (space science, space applications and military activities) and the organization and economic implications of the Soviet space program will be delivered to you in late summer as previously agreed.

For Volume 1, Marcia S. Smith, Specialist in Aerospace Policy, Science Policy Research Division, wrote the material concerning piloted space programs and the executive summary; Courtland Lewis, consultant, wrote the chapter on space life sciences; and Geoffrey E. Perry, head of the Kettering Group in England, wrote the sections on launch vehicles, launch sites and tracking support. Max White, a member of the Kettering Group, wrote the appendix on Soviet tracking ships in their space support role. Ms. Smith served as the coordinator for the report. Mr. Christopher H. Dodge, Specialist in Life Sciences in SPRD, provided overall guidance to Mr. Lewis.

All the material in this report was obtained from unclassified sources. Most of the references to written Soviet sources are available in English through the Foreign Broadcast Information Service.

We hope that this report will assist you in your continued assessment of Soviet space activities as they relate to the United States space program.

Sincerely,

JOSEPH E. ROSS,
*Director.*

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# EXECUTIVE SUMMARY

Since the last edition of this report, the Soviets have continued to make steady strides toward their goal of having a permanently occupied space station in Earth orbit. They have introduced two new launch vehicles and continue to develop a space shuttle and a spaceplane. While the dramatic headlines of 1987 in several U.S. newsmagazines were overstated in saying that the Soviets had "surged ahead" or "taken the lead" in space, there is no question that they hold a commanding lead in the operational use of crews in Earth orbit.

It seems unfortunate that 30 years after the launch of Sputnik sparked a "space race" between the superpowers that space activities are still so often characterized in those terms. Space has long since ceased to be a matter of concern to only those two countries, of course. China, India, Japan and the 13-member countries of the European Space Agency have demonstrated the ability to place satellites into orbit. Those countries, plus others like Canada, have growing space industries as well. Thus, to think of a "space race" between only two countries is a decidedly narrow view.

The concept of "racing" itself may be inappropriate in today's climate. Although it seems inevitable that countries will use space as a method of engendering national pride, a prime motivation for racing with each other, the allure of international cooperation is receiving increasing attention as every country wrestles with economic problems. Countries can accomplish more through cooperation where costs are shared among several partners. The United States led the way in opening space to other countries, and our intent to have an open, international space program is codified in the 1958 National Aeronautics and Space Act. The Soviet Union was much slower in permitting international participation in its activities. While France, Sweden and India have cooperated with the Soviets for many years, it was only in the 1980s that the Soviet program was opened broadly to other countries, some of which have flown representatives on Soviet space station missions. U.S./Soviet space cooperation has waxed and waned over the decades, with the climate today generally good for exchanging space science and space medicine data. Greater cooperation with the Soviet Union does, of course, raise technology transfer concerns, which ironically is leading the United States to reassess the wisdom of international cooperation just as the Soviet Union is touting its benefits.

## WHO'S AHEAD?

Nevertheless, comparisons are inescapable. The question of "who's ahead" has become the battle cry for legions of space enthusiasts seeking to instill life into the U.S. program. There are no simple answers.

No single country is "ahead" of all the others in space. The comparison is different for each aspect of space activities—space science, space applications (military and civilian), operational activities involving crews, and technology for each of these areas. There are also different kinds of competition: economic, military, and national prestige. Determining "who's ahead" requires specifying what type of space activity is being measured and what kind of prize is being sought. It also requires a benchmark against which to judge the contest.

For example, assessing whether the United States or the Soviet Union is ahead in piloted spaceflight can result in at least three answers.

> The United States is ahead in the technology of piloted spaceflight—the Soviets still do not have a space shuttle. Despite the tragic fate that befell Challenger on January 28, 1986, the U.S. shuttle system had flown 24 times successfully prior to that grim day, and will fly again. With their new Mir space station, the Soviets are only now approaching the level of technology the United States had on its Skylab space station, launched in 1973. Mir is simply another derivative of the basic Salyut design used since 1971. The Soyuz TM ferry craft used to take crews to and from the space station is just another modification of the Soyuz used since 1967.
>
> The Soviets are ahead in the operational use of crews in Earth orbit—measured by the amount of time their crews have accumulated in space, the number of hours spent performing experiments, the data they have gained in understanding human reactions to long durations in weightlessness, etc. There is one area in which the two countries are at least tied, however, and perhaps where the United States is ahead: extravehicular activities (EVAs), or spacewalks. Although the Soviets were the first to make an EVA in 1964, they have only begun using them routinely in the past four years, whereas the United States has incorporated such activities into space missions ever since the first U.S. EVA in 1965. Since 1984, the Soviets have accomplished great deeds using EVAs—most notably repairing a leaking fuel valve on Salyut 7 and rescuing the Kvant astrophysics module when it was unable to dock with Mir. The United States, however, has the MMU backpack that allows astronauts to move away from the space shuttle, untethered, and perform satellite retrieval missions. The rescues of the Solar Max, Westar, and Palapa satellites are far beyond what the Soviets can do today.
>
> The Soviets are ahead in meeting announced goals. In the United States, the goal is to have a permanently occupied space station, which will not be achieved until the mid 1990s. The Soviets essentially have that capability today. For the Soviets, the goal is to send people to Mars. Through their long duration space station flights, they have established the only existing data base on the reaction of humans to long durations (now up to 326 days) in weightlessness, and have developed a good understanding of the logistical complexities involved in

maintaining humans in space for long periods. This is not to say they are close to being able to send people to Mars, simply that they have a good start on the research that needs to be done before such a mission is attempted. The United States is doing some research in areas such as closed-cycle life support, but not to the same extent as the Soviets.

Similar problems are encountered in assessing the launch vehicle situation. Many observers point to the fact that the Soviets launch approximately 100 times each year, compared to 15–20 launches in a typical year for the United States, and conclude that the Soviets are ahead. Actually, this comparison shows how far the Soviets are behind, since the difference is primarily attributable to the low level of Soviet technology. They have to launch that many more satellites to accomplish the same objectives the United States can meet with fewer launches. While Soviet technology is improving, and their satellite lifetimes are slowly increasing, they still do not approach the lifetimes achievable with Western technology. With advances in satellite technology, the Soviets may launch fewer satellites as the years go by, just as the United States was able to reduce its number of annual launches.

The test of the Energiya rocket in May 1987 led some Western analysts to conclude that the Soviets were ahead in launch vehicles, but the United States and Soviet Union have each developed launch vehicle fleets to meet their different needs. Neither is "ahead" of the other. In the United States, decisions made in the 1970s to phase out older "expendable" launch vehicles in favor of the reusable space shuttle have been revisited and the United States is now vigorously returning to a "mixed fleet" approach. Many U.S. space advocates rue the decision to curtail production of the Saturn V, but at the time that decision was made, there was no need for that particular vehicle; now that requirements have been identified for a heavy lift launch vehicle, the United States is designing one. The Soviets have a diverse fleet, but it should be remembered that there were 20 years (1965–1985) when there were no new Soviet launch vehicles (their attempts to build a Saturn V-class vehicle in the late 1960s and early 1970s failed). Now the medium lift J (or SL–16) vehicle is operational, and Energiya is in the test phase. Just like the United States, once the Soviets identified requirements for new launch vehicles, they were produced. The technology for Energiya is similar to the Saturn V, so although it is a giant step for the Soviet space program, it brings them only to the point where the United States stood 25 years ago.

These examples illustrate the difficulty in answering the question of who's ahead. A more important difference between the two programs is that the Soviets have tenacity. They do not "surge" ahead in space (as some press reports have indicated). Rather their program is characterized by slow but steady progress made possible by a long term commitment to the program. By comparison, the U.S. civilian space program has been subject to fits and starts since the end of the Apollo program. This has led many to use Aesop's Fable of the Tortoise and the Hare as the analogy for the two space programs.

The Soviet ability to make long term commitments is a function of its form of government. Long range planning is inherently difficult in a democracy where elections are held frequently, changing administrations may alter goals, and annual budget cycles raise the possibility of program cancellation every year. In the Soviet system, relatively few people are involved in setting goals and ensuring they are implemented. One of the prices we pay for a democratic form of government is the ability to change horses in midstream, which complicates long range planning for any government supported activity.

## GLASNOST AND GLAVKOSMOS

The Soviet form of government is experiencing changes under the leadership of General Secretary Mikhail Gorbachev. Glasnost, for example, has definitely affected some aspects of the space program. Announcements of launch dates, launch times and even the names of crews are now made in advance (although sometimes only by hours), and the unprecedented publicity surrounding the first test launch of the Energiya rocket was surprising. In late 1987, Western visitors were allowed at the Tyuratam launch facility and more than a hundred Americans were invited to participate in the Moscow International Space Future Forum in October 1987 to celebrate the 30th anniversary of Sputnik. Soviet scientists, engineers and researchers attending international conferences have been much more willing to talk about their programs.

In fact, this increased openness may be partially responsible for the feeling in the West that the Soviets are so far ahead in space. They are finally telling Western colleagues what they are doing and planning for the future. The effects of glasnost should not be overstated, however—the Soviet space program is far from open. Military space activities are still not discussed (although they have admitted, at last, that they do conduct military space missions), and while they have announced future activities in space science, they have not published a schedule for activities in the piloted space program. They have said nothing about their spaceplane program, nor about the medium lift launch vehicle (J) they introduced in 1985. While they report frequently on what the cosmonauts are doing on space stations in general, details on experimental results are not available. Nor have they ever published figures on how much they spend on space activities. Western estimates that the Soviet program costs one and a half times as much as the United States are riddled with uncertainty (the total U.S. space budget was approximately $26 billion in fiscal year 1987; volume 2 of this report will discuss Soviet space budgets in more detail). Secrecy still surrounds the Soviet space program; it is simply that the blanket is not quite as thick as it once was.

Another interesting development under the Gorbachev administration is the creation of a "civil" space agency, Glavkosmos. Created in October 1985, Glavkosmos is responsible for overseeing what would traditionally be considered civilian space programs—space science, the space station program, and commercial activities. Among the services now being offered by Glavkosmos and associated agencies are launches on any of their vehicles except the two newest models (only one of which is operational now), remote sensing images, and flight opportunities for materials processing experiments. (Details on Glavkosmos and the commercialization of remote sensing and materials processing are provided in Volume 2 of this report.)

## RECENT PROGRESS

Since the last publication of this report, the Soviets have made substantial progress in piloted space programs (including the space life sciences) and launch vehicles. In summary, the Soviets:

Launched a third-generation space station, Mir, with six docking ports, which gives them a much more versatile research laboratory in space where modules can dock for long or short periods of time, and experiments can be changed as research directions change.

Extended the duration of human spaceflight to 326 days, providing them with a better understanding of the human reaction to long durations in weightlessness (physiological and psychological); of methods to close the life support system by recycling air and water and growing plants; and of the logistical aspects of maintaining human life in space for long periods of time.

Continued development of a reusable space shuttle—and acknowledged that they were doing so, even stressing that Anatoliy Levchenko's visit to Mir in December 1987 was related to testing his piloting skills for future space shuttle flights.

Launched two more biosatellite missions to expand their knowledge of space medicine.

Substantially increased their use of extravehicular activity (EVA), including major repairs to the Salyut 7 space station, adding solar panels to increase electrical supply to Salyut 7 and Mir, and rescuing the Kvant astrophysics module when docking problems arose.

Resurrected Salyut 7 after it suffered an electrical short circuit that left the station frozen and unable to communicate with ground control or an approaching Soyuz.

Coped with two medical emergencies, one of which ended a mission prematurely and the other resulted in the replacement of the crew member with someone new.

Performed wide ranging experiments in materials processing and space medicine; made astronomical and remote sensing observations; and tested procedures for welding, soldering, cutting and constructing in space.

Introduced the use of a relay satellite for communicating between the Mir space station and ground control.

Introduced a new medium lift launch vehicle, and

Tested a new heavy lift launch vehicle, Energiya, similar to the U.S. Saturn V.

## MISSING ELEMENTS

Speculating on what the Soviets will do in the near future to improve their piloted and launch vehicle programs produces a list rather easily. First, the modules for Mir seem to be taking much longer to produce than expected. The modules themselves are based on the Salyut design, so their production should not be a problem. Rather, the scientific equipment may be the pacing item. The Soviets have indicated that the next module will be for remote sensing, followed by a module dedicated to materials processing, and next the Medilab module for medical experiments. At the present rate, Mir will not be fully utilized until well into the 1990s.

Even now, however, electrical consumption is a problem. As more modules are added to the space station, and possibly larger crews, the demand for electricity will increase. The Soviets have discussed the possibility of building dedicated solar power satellites for generating and transmitting electricity to other space facilities. When these will be developed is unclear; until then, they will have to rely on electricity from solar panels on the space station and associated modules which may limit the experiments they can conduct.

Relief from the time consuming operational and maintenance chores crews must perform on the space station to allow more time for experiments is also probably a high priority. It is amazing that the crews are able to do as much as they have, considering the number of times they are interrupted by cargo flights that must be unloaded and then reloaded with trash, visiting crews (who may be a welcome relief from the monotony of space station existence but nevertheless disrupt the routine), and by EVAs to perform tasks outside the station. Coupled with the decreased productivity of the cosmonauts as the mission progresses (by the end of Romanenko's 326 day mission, his working day had been cut to only 4–4.5 hours because of fatigue), the amount of time for experiments is relatively small.

Even when they are able to perform experiments, the lack of routine opportunities to return the results to scientists on the ground has slowed the pace of their research. Why they have not continued to use the system demonstrated in 1983 with Cosmos 1443, which had its own capsule for returning material to Earth, is a mystery. Coupled with the time-consuming analysis of results and decisions on what experiments to do next, progress toward "space industries" has been tediously slow. This is not to diminish what they have accomplished—if nothing else, they have learned what the constraints are so someday they can be overcome.

Getting the space shuttle operational will clearly help with the space-to-Earth transportation problem, as well as give the Soviets even greater flexibility in operating in Earth orbit. The Soviets have finally admitted that they are building the shuttle, but have not said when they will conduct the first launch. Since its Energiya launch vehicle is not yet operational, and probably will not be until late 1988 or 1989 at the very earliest, a shuttle launch in 1988 would be surprising. When Energiya is operational, many opportunities will be opened for the Soviets both in low Earth orbit and, if they choose, at destinations much further away.

Once they have a space shuttle, they probably would like associated devices like the MMU backpack to make untethered EVAs and a remote manipulator system (the "arm") for moving objects into and out of the shuttle cargo bay, as has already been repeatedly demonstrated by the United States.

Where the rumored spaceplane would fit into the program is unclear. Perhaps it is part of the development program for the space shuttle and will not be pursued as a separate vehicle. It also might be more a part of the military space program (discussed in Volume 2 of this report) for military sortie missions and other such activities. At this point, its purpose and schedule cannot be deduced.

For the longer term, the Soviets have clearly stated their interest in sending crews to Mars, and recently have revived discussions of trips to the Moon as well. In fact, the head of cosmonaut training, General Shatalov, has connected the two concepts, suggesting that crews returning from Mars might need to stay on the Moon for perhaps a month to begin readapting to gravity. When a Mars mission would be undertaken depends upon many factors—economic, technical and logistic considerations, and politics—and it is not clear whether it would best be undertaken by the U.S. and Soviets jointly, by those two countries in parallel but separate missions to reduce technology transfer concerns, or in cooperation with other space-faring countries. The Soviets clearly are not ready to send crews to Mars today. Not only are they lacking the logistical solutions to maintaining life for such a long period in space, but they are still developing the data base to determine whether crews could survive 2–3 years in transit. Radiation protection will have to be provided since they will be far from the protective environment of the Earth's atmosphere and magnetosphere, and the ability to readapt to Earth's gravity upon return must be assured. They are researching these issues, however, so a decision could be expected in the early 1990s as to when they might go.

## THE EFFECT OF SOVIET SPACE ACTIVITIES ON U.S. SPACE POLICY

Some space advocates today appear determined to create another Sputnik environment in which the American public reacts with alarm at the alleged Soviet lead in space. The hope seems to be that such an environment will spur the U.S. Government to spend more money on the civilian space program than it otherwise might spend during these difficult budget times.

Despite the headlines of the past few months, the Soviets have not suddenly taken the lead in space. They are clearly ahead in one area—operations with crews in low Earth orbit—and they have been ahead in this area since the late 1970s. At that time, the United States chose not to launch any crews into orbit while awaiting the space shuttle. The Soviets were redoubling their efforts at that time. At the end of the Apollo era in 1975 (the Apollo-Soyuz Test Project), the United States had 22,504 cumulative hours of time in space. The Soviets had 10,740 hours. By the time of the first U.S. space shuttle flight in 1981, the Soviets had 50,860 hours while the U.S. total remained the same. The Challenger tragedy is not what allowed the Soviets to obtain a lead in this area, and the return of the space shuttle to service will not narrow the gap. If the United States chooses to compete with the Soviets in this area, it must have the ability to leave crews in Earth orbit for very long periods of time, not the 7–10 days achievable with the shuttle in its current configuration.

It should be stressed that the Soviets do not lead in the technology involved in using Earth orbit. Their crews are able to compensate for their limited technological sophistication, and they are making steps towards increasing the level of technology on their space station. Still, they are only now beginning to have a space station with the technical capabilities of the 1973 U.S. Skylab. This is not to preach complacency, however. The Soviets are not standing still. Their level of technology is gradually increasing and they have demonstrated the ability to overcome technological shortcomings in any case.

The United States needs to make its own space policy to meet its needs, rather than simply react to what others are doing. The U.S. response to Sputnik (and to Yuriy Gagarin's flight in 1961) must be held at least in part responsible for the policy dilemma in which the United States finds itself today. The short term goal chosen to win the space race then—the Apollo program—was met and American technological superiority was demonstrated. The aftermath of Apollo, however, has been a continued search for goals and the resultant "fits and starts" experienced by the civilian space program. Resolution of U.S. space policy issues requires identification and articulation of goals that are good for the United States, regardless of what others are doing.

# PART ONE: PILOTED SPACE ACTIVITIES

# CHAPTER 1—HISTORICAL SUMMARY [1]

Soviet interest in sending humans into space was evident very early in the Soviet space program. Well before Yuriy Gagarin's 1961 spaceflight, the Soviets had shown their interest in the possibility of piloted [2] space activities by experimenting with animal flights both in sounding rockets and in spacecraft. The detailed history of Soviet piloted space activities through 1983 (along with footnote references for the material contained in this chapter) can be found in *Soviet Space Programs: 1976-1980 (with supplementary data through 1983)—Part 2.* A summary is provided here.

## The Beginning: 1957-1960

On November 3, 1957, just one month after the launch of Sputnik 1, the Soviet Union orbited Sputnik 2, the first spacecraft to carry an animal—the dog Laika—into space. Since the Soviets did not know how to recover satellites then, the dog was poisoned by a prearranged system after a week of tests.

Sputnik 2 had been preceded by a series of flights using sounding rockets in which the Soviets lofted primarily dogs, but occasionally rabbits, to very high altitudes. Tests using animals continued after Sputnik 2, both with sounding rockets and satellites (the Korabl Sputnik 1-5 series), finally leading to the launch of the first human into space.

## The Moon Race Era: 1961-1970

Yuriy Gagarin became the first human to orbit Earth on April 12, 1961.[3] This was the first flight of the Vostok series, which ulti-

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[1] Previous editions of this report have been self-contained, with each new version repeating all the historical information from past editions. As the years have progressed, it has become increasingly weighty to follow this practice. Therefore, beginning with this volume, only new activities will be described in detail. Individuals interested in reading the previous editions (Soviet Space Programs 1962; Soviet Space Programs 1962-1965; Soviet Space Programs 1966-1970; Soviet Space Programs 1971-1975 (2 volumes); and Soviet Space Programs 1976-1980, with supplementary data through 1983 (3 volumes)) can access them at U.S. Government depository libraries, which include most university libraries and libraries in major cities. All were published by the U.S. Government Printing Office for the Senate Aeronautical and Space Sciences Committee (through the 1971-1975 volumes) or the Senate Commerce, Science, and Transportation Committee (the 1976-1980 volumes) which assumed jurisdiction for space matters from the Aeronautical and Space Sciences Committee in 1976.

[2] As more and more women join the ranks of space crews, the terms "manned" and "unmanned" spaceflight have become anachronistic. Finding suitable synonyms is problematical, however. In this report, "piloted" spaceflight will be used instead of "manned" spaceflight to indicate missions that involve human crews. "Automated" will replace "unmanned" space activities. While there are imperfections in the use of these terms as well, they at least do not have a gender bias.

[3] From April 2-6, 1986, as part of the celebration of the 25th anniversary of Gagarin's flight, a five-part series of articles was published in Izvestiya detailing the early development of the Soviet piloted space program, the selection of the first cosmonauts, and the choice of Gagarin as the first man to go into space. The most interesting revelation in the series was the admission that one cosmonaut died prior to Gagarin's flight in a training accident (the main thrust of the article is a refutation of some Western claims that cosmonauts had died in spaceflight prior to

Continued

mately included six missions between 1961 and 1963. Vostok 6, the last of the series, carried the first woman, Valentina Tereshkova, into space.

The Vostok program established the basis for planning longer and more complex space missions. It was followed by the Voskhod program, of which there were only two flights from 1964–1965. The first of these involved the first multiple crew (three-people), while the second demonstrated the feasibility of extravehicular activity (EVA, or spacewalks) when Aleksey Leonov became the first man to make an EVA in March 1965.

From then until April 1967, there were no Soviet piloted spaceflights, despite the fact that the Soviet Union was apparently engaged in a "race" to the Moon with the United States following President Kennedy's 1961 speech. For its part, the United States conducted 10 Gemini missions between 1965 and 1966 to gain experience related to the lunar landing goal, following the 1961–1963 Mercury program which had objectives similar to Vostok.

The Soviets, however, were developing a new vehicle for lunar missions—Soyuz. Historically, the Soviets test spacecraft intended for use by crews in an automated mode first, and two Cosmos [4] flights, in November 1966 and February 1967, are counted as tests of the new craft.

The first Soyuz spacecraft to actually carry a cosmonaut was destined to become the first space tragedy for the Soviet Union. On April 24, 1967, Vladimir Komarov was killed upon impact with the Earth when the parachute lines of his Soyuz 1 spacecraft tangled during descent after 18 orbits of the Earth. The Soviets return their crews to land (rather than water as the United States did at that time) and the spacecraft struck the surface with great force.[5] Ironically, just three months earlier a tragic fate had awaited the crew of the first U.S. Apollo mission. The three-man crew was killed when a fire erupted in their spacecraft during pre-launch tests.

The U.S. program was shut down for 21 months, the Soviet program for 18 months. Finally, in October 1968, both countries resumed piloted space flights. For the Soviets, it was a relatively simple rendezvous between the automated Soyuz 2 and Soyuz 3,

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Vostok 1). The man who died, Valentin Bondarenko, had completed a ten day stay in an isolation pressure chamber. The chamber had an oxygen-rich atmosphere to compensate for the decreased pressure, and as he was leaving, he removed sensors that had been attached to his body and wiped the areas with cotton soaked with alcohol. He accidentally threw one of the cotton balls onto an electric heating plate and fire erupted. Before the door could be opened, the pressure had to be equalized and by the time rescuers could reach him, it was too late. He was conscious when they removed him, but he died eight hours later.

There was another interesting anecdote about Grigoriy Nelyubov, chosen along with Gagarin, who did not react well to Gagarin being selected to fly first, and Titov to fly second. After Titov's flight, he got into trouble with the Military Police along with two other cosmonauts, was given an opportunity to apologize but refused, resulting in the expulsion of all three from the cosmonaut corps. He became bitter, and in 1966 was run over by a train while he was drunk.

On March 23, 1987, an article in Pravda recounted the investigation into Gagarin's 1968 death while he was piloting a UTI MIG–15. The investigation, which had not been made public before, concluded that the crash was caused by pilot error complicated by two different cloud layers in which the flight took place. Instructor pilot Vladimir Seregin was also killed.

[4] Cosmos is the Russian word for space and is used generically for Soviet spacecraft whose mission is experimental, scientific, military, or in some other way does not merit a distinct name such as Soyuz. By the end of 1987, there had been over 1800 spacecraft designated Cosmos.

[5] The velocity was so great that the pilot undoubtedly would have been killed whether the spacecraft hit land or water.

which carried one cosmonaut. The ships did not dock, despite expectations in the West that this was the intended goal since there had been automated tests of docking procedures under the Cosmos designation (Cosmos 186 and 188, and Cosmos 212 and 213) in 1967 and 1968. By contrast, the first U.S. piloted flight after the Apollo fire was a complete test of the Apollo command module in Earth orbit, and two months later, a three-man crew orbited the Moon. It was clear by the end of 1968 that the United States was well ahead in the Moon Race.

The next Soviet piloted launches, Soyuz 4 and 5 in January 1969, were a step forward for the Soviets, however. The two craft docked, and two of the cosmonauts who had been launched in Soyuz 5 transferred via EVA into the Soyuz 4 spacecraft, joining its pilot for return to Earth. The Soviets hailed this as the first "space station," a label rejected in the West since the crew could not move from one section of the "station" to the other without EVA.

July 1969 saw the United States officially win the race to the Moon as Neil Armstrong and Buzz Aldrin took their first steps on the lunar surface. By contrast, the Soviet program was still at a stage of development similar to the U.S. Gemini program.

Despite later Soviet assertions that they had never intended to send people to the Moon because samples could be returned by automated devices (which the Soviets did three times between 1970 and 1976), the record strongly suggests that they were indeed attempting to develop the systems to accomplish such a goal. For example, five missions using the Soyuz spacecraft, but labeled Zond (Zond 4, 5, 6, 7, and 8), were conducted between 1968 and 1970 to develop experience with the recovery of spacecraft on circumlunar missions. The spacecraft carried a variety of animals and the Soviets conceded that these Zond missions were related to developing the capability to send people around the Moon. From 1970 to 1971, four missions under the Cosmos label were launched which also were apparently related to developing systems for lunar missions. When the last of these, Cosmos 434, reentered in 1981, the Soviets stated that it had been a test of a lunar cabin, confirming long-held Western assessments.

The Soviet inability to win the Moon race is usually attributed to their failure to develop a launch vehicle as capable as the U.S. Saturn V which was used to send the Apollo crews to the Moon. Press reports in the late 1960s and early 1970s discussed three alleged failed tests of a Saturn-V class launch vehicle, dubbed the "G" booster in the West, and a successful test was never achieved.

As the United States continued its Moon landings, the Soviets turned their attention to Earth orbit. Soyuz 6, 7, and 8, launched in October 1969, were heralded as a group flight that tested the capabilities of Soviet tracking and communications support. The three were launched on successive days and each remained in orbit for five days. Western expectations that Soyuz 7 and 8 would dock were not realized. Soyuz 6 carried a welding experiment, Vulkan, which is still cited today as the first experiment related to materials processing in space.

In 1970, Soyuz 9 established a new duration record for piloted spaceflight: 18 days. While short by today's standards, data from Soyuz 9 proved valuable in planning future Soviet piloted missions.

The poor physical condition of the crew upon return led to the institution of an exercise regime on long-duration flights to keep the human body in shape during weightlessness.

TABLE 1.— SUMMARY OF SOVIET FREE-FLYING PILOTED MISSIONS

| Mission | Launch date | Reentry date | Number of crew | Comments |
|---|---|---|---|---|
| Vostok 1 | 04/12/61 | 04/12/61 | 1 | First human in space—Yuriy Gagarin. Completed 1 orbit. |
| Vostok 2 | 08/06/61 | 08/07/61 | 1 | Completed 17 orbits. |
| Vostok 3 | 08/11/62 | 08/15/62 | 1 | Co-orbit with Vostok 4. |
| Vostok 4 | 08/12/62 | 08/15/62 | 1 | Co-orbit with Vostok 3. |
| Vostok 5 | 06/14/63 | 06/19/63 | 1 | Co-orbit with Vostok 6. |
| Vostok 6 | 06/16/63 | 06/19/63 | 1 | First woman in space—Valentina Tereshkova. Co-orbit with Vostok 5. |
| Voskhod 1 | 10/12/64 | 10/13/64 | 3 | First multiple-person crew. |
| Voskhod 2 | 03/18/65 | 03/19/65 | 2 | First extravehicular activity—Aleksey Leonov. |
| Soyuz 1 | 04/23/67 | 04/24/67 | 1 | First death in a spaceflight—Vladimir Komarov. |
| Soyuz 2 | 10/25/68 | 10/28/68 | 0 | Automated spacecraft for rendezvous with Soyuz 3. |
| Soyuz 3 | 10/26/68 | 10/30/68 | 1 | Rendezvous with Soyuz 2. |
| Soyuz 4 | 01/14/69 | 01/17/69 | 1 | First docking of two piloted spacecraft. Two crew from Soyuz 5 transferred via EVA into Soyuz 4 for return. |
| Soyuz 5 | 01/15/69 | 01/18/69 | 3 | (See Soyuz 4.) |
| Soyuz 6 | 10/11/69 | 10/16/69 | 2 | First materials processing experiment (welding). Group flight with Soyuz 7 and 8. |
| Soyuz 7 | 10/12/69 | 10/17/69 | 3 | Group flight with Soyuz 6 and 8. |
| Soyuz 8 | 10/13/69 | 10/18/69 | 2 | Group flight with Soyuz 6 and 7. |
| Soyuz 9 | 06/01/70 | 06/19/70 | 2 | New duration record of 18 days. |
| Soyuz 12 | 09/27/73 | 09/29/73 | 2 | Test of modifications following Soyuz 11 tragedy. |
| Soyuz 13 | 12/18/73 | 12/26/73 | 2 | Astronomical studies. |
| Soyuz 16 | 12/02/74 | 12/08/74 | 2 | Test of modifications for Apollo-Soyuz Test Project (ASTP). |
| Soyuz 19 | 07/15/75 | 07/21/75 | 2 | Soviet part of ASTP. |
| Soyuz 22 | 09/15/76 | 09/23/76 | 2 | Test of East German multi-spectral camera. |

Prepared by Marcia S. Smith, CRS.

## The Space Station Era Begins: 1971–1977

### SALYUT 1–3 AND COSMOS 557; SOYUZ 12 AND 13

In 1971, the space station era began with the launch of Salyut 1. The crew of the first spacecraft to dock with the new space station, Soyuz 10, was unable to open the hatch between the two vehicles and returned home with their mission unfulfilled. The three-man crew of Soyuz 11 was more successful, and spent three weeks on the station performing a wide variety of experiments. On June 29, 1971, however, the Soyuz 11 mission became the second space tragedy for the Soviets. An improperly closed valve allowed the cabin's atmosphere to vent into space during reentry and the cosmonauts died of asphyxiation. The Soviets had abandoned the requirement for wearing spacesuits during launch and reentry because of confidence in their technology and the operational consideration that three space-suited cosmonauts could not fit inside the Soyuz as it was then configured. Following the Soyuz 11 tragedy, the Soviets reinstituted the practice of wearing spacesuits, which is still followed today. As a result, only two-man crews were launched until 1980 when the reconfigured Soyuz-T came into operation.

The Salyut design has remained essentially the same since 1971: it is a cylinder 13.5 meters long and 4.15 meters in diameter at its widest point. The most significant difference over the years is the number of docking ports. Salyut 1–5 had one port; Salyut 6 and 7 had two.[6] The placement of solar panels for generating electricity changed from Salyut 1 to Salyut 3, but has remained the same since, with a total of three panels in two planes. During the Salyut 7 era, Soviet crews began to install additions to the existing solar arrays to increase electrical power. The maximum electric power level available on Salyut 7 was 7 kilowatts (kw)—4 kw from the original arrays and 3 kw from those added by the crews. Once the Soviets complete the use of a space station, they deorbit it into the Pacific Ocean. The Soviets have followed this procedure with each of their space stations except Salyut 7 which is still in orbit even though the Soviets stated in 1986 that they do not plan to occupy it again (see Chapter 2, Soyuz T–15).

The early years of the 1970s were difficult for the Soviets. Following the loss of the Soyuz 11 crew, 27 months elapsed before the next piloted flight, Soyuz 12, was made in September 1973. Several automated tests of Soyuz had been flown in the intervening months under the Cosmos label, and Soyuz 12 tested the modifications with a crew. It also introduced a new variant of the Soyuz for use in ferry missions to space stations: it had no solar panels since batteries were deemed sufficient for the short travel times to and from the station.

Soyuz 12 had been preceded by two more failures in the program, however. In April 1973, Salyut 2 was launched, but it broke apart in orbit before it could be occupied. In May, another space station failed so early in its mission (of still unannounced causes) that it was given a Cosmos rather than Salyut designation (Cosmos 557).

With no space station, but a requalified Soyuz, the Soviets launched Soyuz 13 in December 1973 as a free-flyer to enable at least some research objectives (primarily in astronomy) to be met. Thus, by the end of 1973, the Soviet piloted space program was back in business.

In 1974, the fourth Soviet space station, Salyut 3, successfully achieved orbit. It was occupied by one crew (Soyuz 14) while another (Soyuz 15) was unable to dock, apparently because of the failure of a new automated docking system. This demonstrated one of the disadvantages of removing the solar panels from Soyuz. After the failure, the crew had insufficient electrical power to remain in orbit and try again.

Nevertheless, Salyut 3 did signal renewed health in the piloted space program. It was also the first space station apparently dedicated to military objectives. Salyut 3 was placed in a lower orbit than Salyut 1; only military personnel were included in the two crews sent to the station, rather than a combined military/civilian crew as had been the case with Salyut 1; the crew switched to military communication frequencies rather than remaining on civilian channels as they had done with Salyut 1; and after the space station was unoccupied for a month, it ejected a capsule that was recovered on the ground, a procedure similar to methods for returning film from reconnaissance satellites. Although the Soviets insisted that the space station's mission was Earth resources investigations, it was categorized in the West as the first military space station.

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[6] The Mir space station (see chapter 3) is still the same design as the Salyuts; the only major changes are that it has six docking ports, increased electrical power, and relies more on computers.

### SALYUT 4 AND THE APOLLO-SOYUZ TEST PROJECT

Salyut 4, a civilian space station, was launched in 1974 as well. It was occupied by two crews, Soyuz 17 and 18, in 1975. This time frame saw two interesting events in the Soviet space field: a near tragedy with a crew, and the successful completion of the joint U.S./Soviet Apollo-Soyuz Test Project.

The near tragedy occurred on April 5, 1975 as the Soviets attempted to launch a new crew to Salyut 4 following the return of the Soyuz 17 mission. The crew of two lifted off from the Tyuratam launch facility without incident, but during ascent to orbit, the third stage of their usually reliable A-2 launch vehicle malfunctioned. The launch was aborted and the crew landed 320 kilometers north of the Chinese border in Siberia. Had the mission gone successfully, it would have been numbered Soyuz 18, but the Soviets designated it "the April 5th Anomaly." In the West, it is commonly referred to as Soyuz 18A.

The publicity surrounding Soyuz 18A was heightened because it occurred so close to the launch of the joint US/Soviet Apollo-Soyuz Test Project (ASTP). Formally started in 1972 following a summit between President Nixon and Soviet Premier Brezhnev, ASTP was a tribute to detente, the warming of relations between the two countries. Although touted as an opportunity to conduct joint research, it is generally accepted that ASTP had more to do with political than scientific goals, though experiments were conducted by both countries. Concern about the Soyuz 18A failure and its implications for ASTP led to strong criticism of the project by some members of Congress, who also expressed reservations that at the same time the ASTP mission would be in orbit, the Soviets would have another crew (the one actually numbered Soyuz 18, launched on May 24) in space aboard Salyut 4. These concerns were alleviated somewhat with the realization that no Americans would be aboard the Soyuz as it ascended to orbit and assurances by NASA that the two missions would have a tracking overlap of only two minutes. Also, the Soviets had committed two launch vehicles and Soyuz spacecraft, both ready simultaneously should one fail, to ensure that a Soviet crew would be in orbit to dock with Apollo. As a further demonstration of their commitment to ASTP, they had flown a special mission, Soyuz 16 in 1974, to test changes to the Soyuz to make it more compatible with the Apollo in terms of atmosphere. The Soviet ASTP mission, launched on July 15, 1987, was numbered Soyuz 19.

ASTP was successful in showing that the two space rivals could work together in orbit, although no joint projects of similar magnitude have been approved since. (U.S./Soviet space cooperation will be discussed in more detail in Volume 2.)

The Soyuz 18 crew was the last to occupy Salyut 4, although Soyuz 20 later docked with the space station. It carried a variety of animals, but no humans, and remained in space for 90 days. This is generally considered in the West to have been a Soyuz test to determine if it could remain in space for 90 days and successfully return to Earth. It did, and heralded an era of longer duration space station stays for Soviet crews.

The Soyuz 17 and 18 crews performed a wide range of experiments on Salyut 4 with X-ray astronomy, biological sciences, atmospheric studies, and some remote sensing of the Earth. In an experiment with ramifications for future operations, the Soviets sprayed a new reflective coating on the surface of a solar telescope that had become degraded during the flight. Further experiments of this nature were conducted on later space stations. The crew also studied the stability of liquids under rotation.

### SALYUT 5 AND SOYUZ 22

The sixth Soviet space station, Salyut 5, was launched in 1975. Since it had characteristics similar to Salyut 3, it is classified in the West as a military space station. Two crews successfully occupied the station (Soyuz 21 and Soyuz 24), while another crew (Soyuz 23) was unable to dock. A capsule was ejected and recovered the day after the final crew left.

The crews conducted several experiments in addition to their observations of the Earth. Some were related to materials processing, including use of the Kristall furnace (advanced versions of this furnace were flown on later space station missions) for growing crystals from potash alums; studies of mass transfer in a melt (tolane-dibenzyl); the crucibleless solidification of a eutectic (lead-tin-zinc-cadmium); brazing of metals using exothermic heat sources (stainless steel, manganese); and studies of the influence of capillary forces in microgravity and behavior of gas inclusions in a liquid (copper, air, water).[7]

Also during this period, the Soviets flew a separate mission, Soyuz 22, which was not intended to dock with the space station. This flight was the first piloted mission to carry instruments made outside the Soviet Union. Specifically, it tested the MKF-6 multi-spectral camera built by East Germany for studying the Earth's surface in six spectral bands. Variants of the MKF were later flown on both Salyut 6 and 7.

TABLE 2.—SUMMARY OF SOVIET SPACE STATION MISSIONS: SALYUT 1–5

| Space station | Launch date | Reentry date | Comments |
|---|---|---|---|
| Salyut 1 | 04/19/71 | 10/11/71 | Soyuz 10 crew unable to enter station after docking. Soyuz 11 crew remained on board for 3 weeks, but died while returning to Earth due to improperly closed valve that allowed cabin atmosphere to escape. |
| Soyuz 10 | 04/22/71 | 04/24/71 | |
| Soyuz 11 | 06/06/71 | 06/29/71 | |

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[7] A historical review of Soviet space-based and sounding rocket materials processing experiments is contained in: Avduyevsky, V.S. ed. Scientific Foundations of Space Manufacturing. Moscow, MIR Publishers, 1984. (In English). Although detailed results of specific experiments are not provided, the book and its companion volume "Manufacturing in Space: Processing Problems and Advances" published by MIR in 1985 (also in English) give a fairly comprehensive overview of the status of materials processing in the Soviet space program.

TABLE 2.—SUMMARY OF SOVIET SPACE STATION MISSIONS: SALYUT 1–5—Continued

| Space station | Launch date | Reentry date | Comments |
|---|---|---|---|
| Salyut 2 | 04/03/73 | 05/28/73 | Broke apart in orbit before it could be occupied. |
| Cosmos 557 | 05/11/73 | 05/22/73 | Failure. |
| Salyut 3 | 06/24/74 | 01/24/75 | Hosted Soyuz 14 crew; Soyuz 15 could not dock. First "military" space station by Western analysis. Capsule ejected from station and recovered 09/23/74. |
| Soyuz 14 | 07/03/74 | 07/19/74 | |
| Soyuz 15 | 08/26/74 | 08/28/74 | |
| Salyut 4 | 12/26/74 | 02/02/77 | Hosted Soyuz 17 and 18 crews. Soyuz 18A suffered third-stage malfunction enroute to orbit. Automated Soyuz 20 docked for 90 days while station unoccupied. "Civilian" space station. |
| Soyuz 17 | 01/10/75 | 02/09/75 | |
| Soyuz 18A | 04/15/75 | | |
| Soyuz 18 | 05/24/75 | 07/26/75 | |
| Soyuz 20 | 11/17/75 | 02/16/76 | |
| Salyut 5 | 06/22/76 | 08/08/77 | Hosted Soyuz 21 and 24 crews; Soyuz 23 could not dock. "Military" space station. Capsule ejected and recovered 02/26/77. |
| Soyuz 21 | 07/06/76 | 08/24/76 | |
| Soyuz 23 | 10/14/76 | 10/16/76 | |
| Soyuz 24 | 02/07/77 | 02/25/77 | |

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## SECOND-GENERATION STATIONS—SALYUT 6 AND 7: 1977–1983

Salyut 6, launched in September 1977, was the first of the second-generation Soviet space stations. Although the essential design of the space station remained the same, Salyut 6 had a major improvement: the introduction of a second operational docking port. With the second port, the Soviets were able to send resupply flights to the space station and to send visiting crews who would remain on board for a week.

The resupply cargo vehicle is a modified Soyuz with the life support systems and heat shield removed to maximize the volume and weight available for cargo. Called Progress, it has the disadvantage of being a one-way vehicle only—it burns up during reentry since there is no heat shield. Thus the Progress vehicles cannot be used to return material to Earth, such as the results of the various experiments conducted by space station crews. Progress made its first flight in 1978 and was used to transfer fuel into the tanks of the space station, the first time an in-space fuel transfer was accomplished.

With Salyut 6, the Soviets had created a facility that could remain operational for much longer periods of time than the previous space stations. In fact, it operated for almost 5 years until it was replaced by its cousin, Salyut 7, in 1982. Since the space stations were so similar, their missions through the end of 1983 will be discussed jointly here. Salyut 7 operations from 1984 to 1986 are discussed in Chapter 2. In 1979, the Soviets introduced a new variant of the Soyuz spacecraft, designated Soyuz T. The last flight launched under the original designation was Soyuz 40 in 1981. All flights to Salyut 7 were made on Soyuz T spacecraft.

During the Salyut 6 era, crews extended the duration of piloted space activities to 185 days. This was increased to 237 days on Salyut 7. The crews performed a wide variety of experiments in materials processing, earth resources, biology and astronomy. They are summarized below.

During most of the Salyut 6 era, the United States made no piloted spaceflights. From ASTP in July 1975 to the first U.S. space shuttle flight in April, 1981, Soviet crews had Earth orbit to themselves. The Soviets achieved a substantial lead over the United States in using crews in Earth orbit during this period of time. One way to compare the piloted programs is to look at how many hours crews have spent in space. At the end of ASTP, the U.S. total stood at 22,504 hours while the Soviets had 10,740 hours. When the first U.S. shuttle was launched, the United States had the same 22,504 hours, but the Soviets had grown to 50,860 hours.

The Soviet accomplishments were not achieved without difficulty, though. The first crew sent to Salyut 6 (Soyuz 25) was unable to achieve a hard dock; Soyuz 33 in 1979 had to effect an emergency return to Earth when one of its engines failed just prior to docking, Soyuz T-8 was unable to dock with Salyut 7, and the Soviets had another near fatal disaster with the first attempt to launch Soyuz T-10.[8] Both space stations required substantial repairs by their crews, who also had to install additional solar panels to Salyut 7 to increase the amount of electrical power available for experiments.

Operational considerations with Salyut 6 and 7 were also daunting, and procedures have not changed with the new Mir space station. For example, visiting crews, who remain on board a space station for a week, usually dock at the aft port since the ferry craft for the main crew is at the forward port. The Soyuz is only rated for approximately 90-days in a powered down condition (as demonstrated by Soyuz 20, although in at least one case—Soyuz T-9—it was somewhat longer), so the long duration crews must switch spacecraft with their visitors to have a new vehicle for the journey home. This means that the visiting crew leaves by the older ship docked at the forward port, leaving the newer spacecraft at the aft port. Progress cargo spacecraft must dock at the aft port, however, since the refueling lines are located there. To free the aft port, the long duration crew must put on their spacesuits, enter the Soyuz, undock, wait while ground controllers rotate the space station 180 degrees, and then redock, now at the forward end of the station. This procedure, still being used in 1987, has become routine, but is time consuming. Added to an already busy schedule for the crew, it is a nuisance at best to have to perform such a procedure several times during a mission.

Another operational inconvenience is the inability of Progress to return material to Earth. The film cassettes from remote sensing cameras, ampules processed in materials processing furnaces, and other experimental results must await the return of the long-duration crew or a visiting crew before being delivered to the scientists on the ground for analysis.

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[8] New details emerged in 1987 about the Soyuz T-10A near-tragedy that occurred on September 26, 1983 (see previous edition of this report). The commander of the mission, Vladimir Titov, and a Soviet journalist described their separate feelings during the emergency in an interview for the Soviet newspaper Krasnaya Zvezda (Red Star) on May 30, 1987. The journalist recalled his reactions at seeing flames envelope the launch vehicle, while Titov recounted his own sensations during the operation of the emergency rescue system (abort tower). He concluded by saying that "We are often asked, was it frightening? I do not know what to answer. I never thought about it. That is the truth!" Later in the year, Lt. Gen. Shatalov, head of the Cosmonaut Training Center, revealed that the crew had experienced an acceleration of 15-17 g's during the escape maneuver, significantly higher than originally assumed by Western observers (8-10 g's). Titov finally succeeded in getting aboard a space station, Mir, at the end of 1987.

Part of the solution to this problem was the development of a modular addition to the space stations that can include a descent portion. The first test of a prototype of this module, to which the Soviets have yet to ascribe a formal name, was Cosmos 929. Launched in 1977, its mission remained obscure to Western analysts until the flights of Cosmos 1267 in 1981 (which docked with Salyut 6 after the final crew had left) and Cosmos 1443 in 1983 (which docked with Salyut 7 before the Soyuz T-9 crew arrived).

At the time of the 1983 mission, the Soviets admitted that Cosmos 929 had been the first of the series, and described Cosmos 1443 as a multipurpose module that could serve as a space tug, moving spacecraft from one orbit to another; a cargo vehicle that could take 2.5 times as much material into orbit as the Progress spacecraft; and as an extension to the space station, adding 50 percent more habitable volume. These modules are approximately the same size as the Salyut space stations, and all three had modules which were detached and recovered on Earth. It is not known what was carried by those related to Cosmos 929 and 1267, but Cosmos 1443 returned 350 kilograms of material, including the results of 45 experiments and pieces of equipment that had functioned on the space station to enable studies of how they had deteriorated.[9] Western analysts have noted the similarity between these "Cosmos 929 type" modules and the "military" Salyut space stations (Salyut 3 and 5) which also ejected capsules for recovery on Earth. It is possible that the Cosmos 929 type modules and the military Salyuts are of the same design, a derivative of the basic Salyut.

## SALYUT 6 AND 7 ACTIVITY SUMMARY: 1977-1983

Salyut 6 was occupied by 16 crews and Salyut 7 by four crews through 1983. Two crews were unable to dock with Salyut 6 and one with Salyut 7. Eighteen Progress missions resupplied the space stations, and there were two Cosmos 929 type modules that docked with them.

Of the missions, eight were the main crews who remained on board for relatively long periods of time or had specific tasks to accomplish: Soyuz 26/27, Soyuz 29/31, Soyuz 32/34, Soyuz 35/37, Soyuz T-3, Soyuz T-4, Soyuz T-5/T-7, and Soyuz T-9. The other spacecraft carried the "visiting" crews, some of which were all-Soviet, but many that included representatives from other countries. Between 1978 and 1983, individuals from 10 countries made voyages to Salyut 6 or 7: Bulgaria,[10] Cuba, Czechoslovakia, East Germany, France, Hungary, Mongolia, Poland, Romania, and Vietnam.

Tables 3 and 4 summarize missions to Salyut 6 and 7 through 1983. As noted earlier, the Soviet main crews often switch spacecraft with a visiting crew. A mission designated Soyuz 26/27, for example, indicates that a crew was launched into space on Soyuz 26, but returned to Earth on Soyuz 27.

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[9] In 1986, the next in the series, Cosmos 1686, was launched to dock with Salyut 7. It did not have a return module. At the end of 1987, it was still docked with Salyut 7 in orbit.

[10] Soyuz 33 carried the Bulgarian cosmonaut. A failure in the Soyuz main engine prevented docking with the space station. The Soviets plan to fly another Bulgarian in 1988.

## TABLE 3.—CREWS SENT TO SALYUT 6 AND 7: 1977–1983

| Mission | Launch date | Reentry date | Duration | Comments |
|---|---|---|---|---|
| SALYUT 6 | | | | |
| Soyuz 25 | 10/09/77 | 10/11/77 | 2 days | Unable to dock. |
| Soyuz 26/27 | 12/10/77 | 03/16/78 | 96 days | Main crew. |
| Soyuz 27/26 | 01/10/78 | 01/16/78 | 8 days | Visiting crew. |
| Soyuz 28 | 03/02/78 | 03/10/78 | 8 days | Visiting crew. First international cosmonaut (Czechoslovakia). |
| Soyuz 29/31 | 06/15/78 | 11/02/78 | 140 days | Main crew. |
| Soyuz 30 | 06/27/78 | 07/05/78 | 8 days | Int'l visiting crew (Poland). |
| Soyuz 31 | 08/26/78 | 09/03/78 | 8 days | Int'l visiting crew (East Germany). |
| Soyuz 32/34 | 02/25/79 | 08/19/78 | 175 days | Main crew. |
| Soyuz 33 | 04/10/79 | 04/12/79 | 2 days | Soyuz engine failure precluded docking; carried a Bulgarian. |
| Soyuz 34 | 06/06/79 | | | No crew aboard; replacement for Soyuz 32. |
| Soyuz T-1 | 12/16/79 | | | Automated test of modified Soyuz. |
| Soyuz 35/37 [1] | 04/09/80 | 10/11/80 | 185 days | Main crew. |
| Soyuz 36/35 | 05/26/80 | 06/03/80 | 8 days | Int'l visiting crew (Hungary). |
| Soyuz T-2 | 06/05/80 | 06/09/80 | 4 days | First flight of Soyuz T with a crew. |
| Soyuz 37/35 | 07/23/80 | 07/31/80 | 8 days | Int'l visiting crew (Vietnam). |
| Soyuz 38 | 09/18/80 | 09/26/80 | 8 days | Int'l visiting crew (Cuba). |
| Soyuz T-3 | 11/27/80 | 12/10/80 | 13 days | Main crew. First 3-man crew since Soyuz 11 tragedy. |
| Soyuz T-4 | 03/12/81 | 05/26/81 | 75 days | Main crew. |
| Soyuz 39 | 03/22/81 | 03/30/81 | 8 days | Int'l visiting crew (Mongolia). |
| Soyuz 40 | 05/14/81 | 05/22/81 | 8 days | Int'l visiting crew (Romania). |
| SALYUT 7 | | | | |
| Soyuz T-5/T-7 | 05/13/82 | 12/10/82 | 211 days | Main crew. |
| Soyuz T-6 | 06/24/82 | 07/02/82 | 8 days | Int'l visiting crew (France). |
| Soyuz T-7/T-5 | 08/19/82 | 08/27/82 | 8 days | Visiting crew—first female cosmonaut since 1963. |
| Soyuz T-8 | 04/20/83 | 04/22/83 | 2 days | Unable to dock. |
| Soyuz T-9 | 06/27/83 | 11/23/83 | 149 days | Main crew. |
| Soyuz T-10A | 09/26/83 | | | Launch abort. |

For continuation of listing of flights to Salyut 7, see Table 7. Missions in bold indicate new endurance record. Reentry date and duration are for the crews, not the spacecraft in which they ferried to the stations.

[1] To set a new record, the FAI (which maintains official records for aviation and space) requires that the previous record be exceeded by 10 percent, so even though this flight was longer than Soyuz 32/34, it was not a new record.

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## TABLE 4.—CARGO AND MODULE FLIGHTS TO SALYUT 6 AND 7: 1977–1983

| Mission | Launch date | Duration | Comments |
|---|---|---|---|
| SALYUT 6 | | | |
| Progress 1 | 01/20/78 | 19 days | 15 days docked. |
| Progress 2 | 07/07/78 | 28 days | 24 days docked. |
| Progress 3 | 08/07/78 | 16 days | 12 days docked. |
| Progress 4 | 10/04/78 | 22 days | 18 days docked. |
| Progress 5 | 03/12/79 | 24 days | 20 days docked. |
| Progress 6 | 05/13/79 | 28 days | 24 days docked. |
| Progress 7 | 06/28/79 | 22 days | 18 days docked. |
| Progress 8 | 03/27/80 | 30 days | 26 days docked. |
| Progress 9 | 04/27/80 | 25 days | 21 days docked. |
| Progress 10 | 07/01/80 | 21 days | 17 days docked. |
| Progress 11 | 09/28/80 | 74 days | 70 days docked. |
| Progress 12 | 01/24/81 | 55 days | 52 days docked. |
| Cosmos 1267 | 04/25/81 | 429 days | Descent module separated 5/24/81; docked with Salyut 6 6/19/81. Salyut 6/C 1267 deorbited together 7/29/82. |
| SALYUT 7 | | | |
| Progress 13 | 05/23/82 | 14 days | 10 days docked. |

TABLE 4.—CARGO AND MODULE FLIGHTS TO SALYUT 6 AND 7: 1977–1983—Continued

| Mission | Launch date | Duration | Comments |
|---|---|---|---|
| Progress 14 | 07/10/82 | 34 days | 30 days docked. |
| Progress 15 | 09/17/82 | 28 days | 24 days docked. |
| Progress 16 | 10/31/82 | 44 days | 41 days docked. |
| Cosmos 1443 | 03/02/83 | 201 days | Docked with Salyut 7 on 3/10/83; undocked 8/16/83; descent module returned 8/23/83; main body reentered 9/19/83. |
| Progress 17 | 08/17/83 | 32 days | 30 days docked. |
| Progress 18 | 10/20/83 | 27 days | 22 days docked. |

For continuation of listing of flights to Salyut 7, see Table 8.

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## SALYUT 6 AND 7 EXPERIMENTS: 1977–1983

The crews of Salyut 6 and 7 spent by far the greatest amount of their experimental time on materials experiments and remote sensing of the Earth. The crews also conducted wide ranging experiments in space biology and medicine (discussed separately), atmospheric studies, and astronomical observations.

### *Materials Processing and Other Materials Experiments*

The Soviets conduct a great many materials science experiments, most of which can be described as materials processing, although some are studies of how materials react to the conditions of spaceflight. For example, the crews will place various materials (rubbers, etc.) in the airlock of the space station for days or weeks to determine how they deteriorate over time.

Of most interest in the West are Soviet experiments in materials processing. During the Salyut 6 era, the Soviets used two furnaces—Splav (Alloy) and Kristall (Crystal)—to conduct over 300 experiments. Among the most often used materials were: gallium arsenide, cadmium- mercury-telluride, indium antimonide, indium arsenide, cadmium sulphide, and germanium. Little is known of the results of these experiments, although the Soviets did announce that space-processed samples of cadmium-mercury-telluride were part of an infrared scanning device used on a late Salyut 6 mission to monitor body temperatures. At least three Soviet books have been published in English on materials processing experiments in the Soviet space program that provide a wealth of information on the science of materials processing in space as understood in the Soviet Union. Regrettably, few specific details are provided on individual experiments, although the books contain tabular summaries of experiments that have been conducted.[11]

Another materials experiment on Salyut 6 used a device called Isparitel (Vaporizer) to study the processes of evaporation and condensation of different materials. Coatings of silver, gold or alloys containing aluminum, copper and silver were sprayed onto metal, glass or plastic with electron guns. This followed the successful experiment on Salyut 4 to recoat the solar telescope.

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[11] The two Avduyevsky books cited in footnote 7 plus: Regel, Lia. Materials Science in Space: Theory, Experiments, Technology. English translation by J.M. Haynes, Bristol University, UK and H. Rodot, CNRS, France. New York, Halsted Press, 1987 (published in Russian in 1984).

On Salyut 7, the emphasis was on electrophoresis experiments using the Tavria unit. The cosmonauts experimented with urokinase and interferon and found it possible to purify substances between 10 and 15 times better than on Earth and the productivity in space was reported to be hundreds of times higher. A superpure protein substance was produced from the membranes of an influenza virus, and Soviet scientists commented that the 35 milligrams produced by the cosmonauts was enough for several months of research, and that it had become a standard against which to compare other vaccines.

Also on Salyut 7, the Pion unit was used to study heat and mass transfer in, and the physics of, multiphase media in weightlessness. The apparatus recorded changes in the density and temperature of substances as the container in which they were held was heated. The processes were recorded on film and videotape using a holographic device.

As already noted, in 1984 the Soviets published a book explaining their current understanding of materials processing in space. In the preface to the book, the editor, V.S. Avduyevsky, summarized the conflicting results that had been obtained:

> The experiments yielded specimens of semiconductors, metals, glasses and medico-biological materials which outperformed similar specimens made with the same equipment on the Earth. However, this improvement was not consistent; sometimes the materials made in outer space would even show substandard performance. Some of the results, on the other hand, came as a surprise, conflicting, as they did, with the theoretical models devised for the experiments.
>
> With this came the realization that there was a need for fundamental research which would lay a scientific basis for further advances in space technology in general and in the preparation of high-performance materials on board space vehicles, in particular.
>
> This book is an attempt to fill the need.[12]

The comments make clear that despite years of experiments, the Soviets have much research to do, and indeed the experiments have continued as discussed in subsequent chapters.

*Remote Sensing*

Although the Soviets can acquire remote sensing images with automated spacecraft, traditionally they have relied on space station crews for the majority of their remote sensing effort. Two permanently installed cameras account for most of the work: the MKF-6M multispectral (6 bands) camera developed by East Germany, and the KATE-140, a wide angle, stereographic, topographical camera for making contour maps. Resolution of the MKF-6M is thought to be about 20 meters. There also were several hand-held cameras and binoculars that the cosmonauts could point out the portholes. In addition, the Bulgarians provided a 15 spectral band spectrometer (Spektr-15) for Earth observations from Salyut 6.

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[12] Avduyevsky, ibid.

The orbital inclination of Soviet space stations (51.6 degrees) does not allow full coverage of the Earth, but the most populated areas can be observed. The Soviets frequently cite the advantages of space platforms for remote sensing compared to surveys using aircraft or other means. From 1977–1980, TASS reported that 9,500 photographs had been taken with the MKF–6M and another 4,500 with the KATE–140. Following the Salyut 6 missions, an article in the Soviet newspaper Izvestiya stated that the economic effect of the remote sensing effort exceeded 56 million rubles and the time required to create cartographic documentation was shortened by 75 to 80 percent. Attention to remote sensing surveys did not diminish during the Salyut 7 missions, and by the end of 1983 another 23,000 photographs had been taken with the MKF–6M and KATE–140 instruments. One improvement on Salyut 7 was the use of a television apparatus called Niva to record and relay information back to Earth so that researchers on the ground would not have to wait until the film cassettes could be returned to Earth.

### *Astronomy*

Only a small amount of time was spent on astronomy during the Salyut 6 and 7 missions. The most important experiment involved deploying a radio telescope from the aft docking port of Salyut 6. Called the KRT–10, it was a 10-meter diameter radio telescope used for three weeks of observations of the Milky Way and Pulsar 0329. Interferometric studies were also conducted in conjunction with a 70 meter telescope in the Crimea. Western scientists familiar with the data from the KRT–10 reported that it was of low quality. One possibility is that the antenna did not fully deploy. When cosmonauts attempted to jettison the antenna to free the docking port, they found that it was caught on part of the exterior of the space station and they had to perform a spacewalk to free it. The Soviets have not clarified whether the problem developed when they unfurled the KRT–10 or when they attempted to detach it.

On Salyut 7, the Soviets used two French astrophysics experiments (Piramig and PCN), an X-ray spectrometer called SKR–02M, and a reflecting X-ray telescope (the RT–4M). The SKR–02M was used for interstellar observations, while Piramig was used for studying the interplanetary medium and galaxies in the visible and near-infrared bands. PCN was used mostly for atmospheric studies, although some observations of astronomical objects were made. Little information is available on the RT–4M.

### *Atmospheric Studies*

Salyut 6 carried the BST–1M submillimeter telescope for atmospheric research. The cryogenically cooled sensors needed to be calibrated each time the instrument was used and the device required a considerable amount of electricity (1.5 kw). As a result, it was used infrequently. Its primary task was to provide data on the ozone layer.

The Yelena gamma ray experiment and the Bulgarian Duga electrophotometer were also used for atmospheric studies on Salyut 6. On Salyut 7, the crews did a small amount of atmospheric studies using the Piramig, PCN and SKR–02M instruments discussed above.

## SPACEPLANE AND SPACE SHUTTLE

By the end of 1983, the Soviets had conducted three tests of a small vehicle dubbed a "spaceplane" in the West. The first two tests, Cosmos 1374 on June 3, 1982 and Cosmos 1445 on March 15, 1983, landed in the Indian Ocean, while the third, Cosmos 1517 on December 27, 1983, landed in the Black Sea.[13] All were launched from Kapustin Yar using the smallest of the Soviet launch vehicles (the "C").

Photographs of the Cosmos 1445 test were released by the Australian government, which apparently had at least one observation ship near the recovery site in the Indian Ocean. The photographs showed a small vehicle, probably a subscale prototype, in the water as well as being brought aboard the Soviet recovery ship. It had a cockpit, strongly suggesting that ultimately it would be used for crews, and an area near the front that appeared to be covered with thermal protection tiles similar to those used on the U.S. space shuttle. The Western press speculated that it would be approximately one-third the size of the U.S. space shuttle when fully developed for operational use.

Through the end of 1983, rumors continued in the West that the Soviets were developing a vehicle the same size and shape of the U.S. space shuttle in addition to the spaceplane, but the Soviets responded to questions about their shuttle program with customary obfuscation.[14]

## SPACE LIFE SCIENCES

### INITIAL UNCERTAINTY

As the Soviet and American space programs were getting under way in the late 1940s and early 1950s, there was considerable controversy among aeromedical specialists as to whether humans could withstand the rigors of space flight. Indeed, many respected experts in medicine and biology held firmly to the belief that piloted spaceflight was impossible—that the human cardiovascular, musculoskeletal, and immune systems would simply fail in the microgravity environment of space. Some also believed that it would not be possible to swallow food. However, other specialists were equally confident that piloted space flight was feasible. They made their case to their respective governments as well as to their doubting colleagues, basing their arguments on simulations, sounding rocket flights, and analyses of physiological system mechanics.

The flight of the dog Laika aboard Sputnik 2 in 1957 broke this impasse. It gave strong evidence that a higher vertebrate physiologically similar to man could survive in space for at least a week. Laika's cabin was instrumented to monitor key biomedical parameters, and the onboard life support systems provided regenerated air and controlled temperature.

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[13] Another orbital test, Cosmos 1614, was made on Dec. 19, 1984 and it landed in the Black Sea. No more orbital tests occurred through the end of November 1987, although the trade press reported that suborbital tests have been conducted. See Chapter 5.

[14] In 1987, the Soviets finally admitted that they were developing a full scale space shuttle (see chapter 5).

## HUMANS ENTER SPACE

Yuriy Gagarin's 1961 flight was the first of six Vostok flights, the primary purpose of which was to establish the basic parameters of human response to spaceflight conditions. Although the series achieved that objective, skeptics remained unconvinced that the human organism would accept exposure to the space environment for more than a few days at best. Much of the concern revolved around the experience of Gherman Titov, in Vostok-2. In his one-day flight, Titov experienced spatial disorientation and motion sickness, the first occurrence of the condition known as "space motion sickness," or SMS (referred to in the U.S. program as "space adaptation syndrome"). Table 5 lists Soviet piloted missions of interest from a biomedical standpoint, from Gagarin's flight through the end of 1983.

Although the Soviets considered SMS a serious problem, their American counterparts were skeptical. Ironically, although most Soviet cosmonauts were experiencing SMS, no American Mercury or Gemini astronaut did. Only during the Apollo era did SMS affect American astronauts, as the classic symptoms of nausea, dizziness, and fullness of the head began to appear during the first hours and days of spaceflight (i.e., the "acute" phase of flight). Eventually it was recognized that the tight confines of the Mercury and Gemini capsules had prevented the head and body movements that precipitate the SMS symptoms. The roomier Soviet spacecraft allowed greater freedom of body movement.

TABLE 5.—SOVIET PILOTED SPACE MISSIONS WITH SIGNIFICANT BIOMEDICAL ASPECTS: 1961–1983

| Mission | Launch date | Duration | Points of biomedical interest |
|---|---|---|---|
| Vostok | 04/12/61 | 1 hr 48 min | First piloted orbital flight. |
| Vostok 2 | 08/06/61 | 25 hr 18 min | First reported space motion sickness. |
| Vostok 3 | 08/11/62 | 94 hr 22 min | Two missions in orbit at once. |
| Vostok 4 | 08/12/62 | 70 hr 57 min | Focus on human functional capabilities for operations in space, comparison of physiological effects on 2 subjects. |
| Vostok 6 | 06/16/63 | 70 hr 50 min | First woman in space. |
| Voskhod 1 | 10/12/64 | 24 hr 17 min | First physician in space. First multi-person crew. Multiple onboard medical studies. Shirtsleeved crew. |
| Voskhod 2 | 03/18/65 | 26 hr 2 min | First Soviet EVA. Studies of neurovestibular function. |
| Soyuz 1 | 04/23/67 | 27 hr | Cosmonaut killed on landing. |
| Soyuz 3 | 10/26/68 | 94 hr 51 min | High heart rates inflight. |
| Soyuz 4 | 01/14/69 | 71 hr 14 min | First successful Soviet docking. EVA transfer. |
| Soyuz 5 | 01/15/69 | 72 hr 46 min | |
| Soyuz 6 | 10/11/69 | 118 hr 42 min | Three missions in orbit at once. |
| Soyuz 7 | 10/12/69 | 118 hr 41 min | Human performance capabilities in space studied. |
| Soyuz 8 | 10/13/69 | 118 hr 41 min | |
| Soyuz 9 | 06/01/70 | 424 hr 59 min | 18-day mission—a new record. Extensive biomedical investigations of cardiovascular, musculoskeletal responses. Exercise regimens tested. Lengthy postflight recovery period. |
| Soyuz 11 | 06/06/71 | 552 hr | First crew to occupy a space station, Salyut 1. All 3 crewmen died of dysbarism due to decompression during reentry. Areas of atrophy in antigravity muscles noted on autopsy. |
| Soyuz 12 | 09/27/73 | 2 d | Return to use of spacesuits. Some weight loss; feeling of chest fullness, uneasy breathing. |
| Soyuz 13 | 12/19/73 | 8 d | Tests of countermeasures for cardiovascular and musculoskeletal deconditioning, including anti-g suits and Penguin suit. Cerebral circulation studied via rheography. Onboard greenhouse. |

TABLE 5.—SOVIET PILOTED SPACE MISSIONS WITH SIGNIFICANT BIOMEDICAL ASPECTS: 1961–1983—Continued

| Mission | Launch date | Duration | Points of biomedical interest |
|---|---|---|---|
| Soyuz 14 | 07/04/74 | 16 d | Docked with Salyut 3. Lung efficiency, cardiovascular changes tested inflight. |
| Soyuz 16 | 12/02/74 | 7 d | Test flight preparing for Apollo-Soyuz changing internal environmental conditions. |
| Soyuz 17 | 01/09/75 | 30 d | Docked with Salyut 4. Evaluated numerous countermeasures. Cerebral blood flow monitored via rheoencephalography. |
| Soyuz 18A | 04/05/75 | | Cosmonauts suffered injuries, exposure when mission aborted enroute to orbit. No fatalities. |
| Soyuz 18 | 05/25/75 | 63 d | Docked with Salyut 4. Continued studies testing human endurance of microgravity. Tested water-salt loading. |
| Soyuz 24 | 02/07/77 | 12 d | Docked with Salyut 5. Evaluated long-term deconditioning countermeasures. |
| Soyuz 26/27 | 12/10/77 | 96 d | First Salyut 6 prime crew. Significant cardiovascular deconditioning postflight. |
| Soyuz 29/31 | 06/15/78 | 140 d | Docked with Salyut 6. EVA suit with minimum prebreathe introduced. |
| Soyuz 32/34 | 02/25/79 | 175 d | Third prime crew of Salyut 6. First reports of recurring SMS inflight and postflight. Radaptation unusually rapid! |
| Soyuz 35/37 | 04/09/80 | 185 d | Fourth and longest-duration prime to Salyut 6. Extremely rapid postflight readaptation. One crewman experienced repeated longduration flight (175 and 185 days), with 6 months in between; no difference in postflight condition noted in the two flights. |
| Soyuz T–4 | 03/12/81 | 75 d | Last prime crew to Salyut 6. Extensive use of mechanical countermeasures for SMS and cardiovascular deconditioning. Onboard clinical analysis equipment used. |
| Soyuz 40 | 05/14/81 | 8 d | Last use of original Soyuz. Last visiting crew to Salyut 6. Tested SMS, cardiovascular countermeasures. |
| Soyuz T–5/T–7 | 05/14/82 | 211 d | First prime crew to Salyut 7. Detailed health maintenance studies. Apparent problems in crew interaction. |
| Soyuz T–6 | 06/24/82 | 8 d | Soviet-French visiting crew. First inflight cardiovascular measurements using echocardiography. |
| Soyuz T–7/T–5 | 08/19/82 | 8 d | Second woman in space. |
| Soyuz T–9 | 06/27/83 | 150 d | First multiple EVAS (two, totalling 6 hours) by a single Soviet crew. |
| Soyuz T–10A | 09/27/83 | | Launch explosion. Crew escaped unharmed using emergency escape tower. |

Prepared by Courtland S. Lewis for CRS.

Following the Vostok flights were two flights of the Voskhod series. Voskhod 1 flew the first three-man crew, among whom was a physician, A.D. Yegorov. This first "space doctor" obtained more sophisticated medical data during the mission, as studies of various physiological parameters were carried out although the flight lasted only one day. Voskhod 2 was notable for the first extravehicular activity. The eight Vostok/Voskhod missions were of short duration; the longest lasted five days. During this era, Soviet biomedical specialists had four main objectives in view:

Provision of adequate life support (i.e., water, breathable atmosphere, adequate diet, and waste management)

Protection of the cosmonaut against the physiological effects of the space environment, and maintenance of normal vital functions

Assurance of cosmonaut safety in the event of space module malfunction

Provision of appropriate measures postflight to ensure optimum readaptation to gravity.

The task appeared relatively simple. The only problem noted thus far by Soviet life scientists was SMS. However, the U.S. Mercury and Gemini programs that parallelled and immediately followed these flights gave evidence of potentially more serious physiological changes. These included a 5–20 percent loss of red blood cell mass and plasma volume (4–9 percent), postflight orthostatic intolerance (i.e., an inability to stand erect), loss of weight and of exercise capacity, inflight loss of bone calcium and muscle nitrogen, along with decreased bone density postflight. These American findings from longer-duration missions helped to shape the biomedical program that the Soviets pursued in their follow-on Soyuz program.

## SOYUZ: SPACE FLIGHT BECOMES ROUTINE

Medical monitoring of cosmonauts during the Soyuz program focused on assessing the physiological effects of microgravity. Cardiorespiratory measurements as well as extensive pre- and postflight examinations were made of the central nervous system, metabolism, blood chemistry, and fluid-electrolyte balance. The cosmonauts themselves became directly involved in the conduct of biomedical experiments. A major setback was experienced with the flight of Soyuz 1, in which the cosmonaut died on impact when his vehicle's drogue parachute failed to deploy properly. When the Soyuz program resumed, following that catastrophic event, the early missions, lasting no longer than 5 days, revealed no unusual or unexpected physiological changes.

However, the flight of Soyuz 9 in 1970 gave rise to renewed concern. This was an 18-day mission, far longer than any preceding it in either the Soviet or American programs. The two Soyuz 9 cosmonauts exhibited pronounced orthostatic intolerance upon reentry and landing, and had to be carried from the space module on stretchers; they required 11 days of postflight readaptation to gravity. This event led to gloomy speculation that the limits of human endurance of space flight had been reached. However, the experience of Soyuz 9 prompted the appropriate response: major emphasis now developed on the use of countermeasures to space "deconditioning" of physiological functions. Subsequent Soyuz missions demonstrated the effectiveness of exercise (using chest expanders, elastic straps, and isometric techniques) and a special "Penguin" suit which provides a constant loading on muscles of the legs and torso.

## SALYUT: THE SPACE STATION ERA

The early 1970s was the beginning of the Salyut space station series. By then, confidence had increased that humans could tolerate missions of relatively long duration. The Salyut stations were intended for long-term habitation by rotating crews. In addition to basic life support systems, facilities were provided for eating, sleeping, personal hygiene, and exercise. The crew of Soyuz 11, in 1971, the first to enter Salyut 1, conducted scientific experiments which included biomedical studies of the long-term response to microgravity. These cosmonauts also investigated exercise as a countermeasure; their 2.5 hours of exercise each day included walking and running on the treadmill with which the Salyut station was equipped. Biological specimens and a hydroponic "farm" for growing plants were on board. Tragically, the three-man Soyuz 11 crew died during reentry. This was the last time that a Soviet crew flew to or from space in "shirtsleeves"; all subsequent flights have required the wearing of a pressurized space suit.

Salyut 3, launched in 1974, had a more "homey" interior design and decor. Physical exercise as a countermeasure was again emphasized by the Soyuz crew that visited it. Medical experiments included studies of cerebral blood circulation and atrial blood velocity. On the next station, Salyut 4, the "Chibis" vacuum suit was worn, for the first time, during exercise and for extended periods during normal activity. This suit applies negative pressure to the lower body, simulating the pull of gravity on the circulatory system, and thereby helping to minimize cardiovascular deconditioning. In addition, a rotating chair was installed for observing vestibular function. A bicycle ergometer ("veloergometer") was onboard for performing exercise and measuring physiological parameters under stress. The last crew to visit Salyut 4 (Soyuz 18) tested a new cardiovascular countermeasure that combined exercise with a high-salt diet and forced intake of water to increase the body's fluid volume in preparation for landing.

By now Soviet space crews had been in space for as long as 63 days at a time. It had been clearly shown that a rigorous program of physical exercise, in combination with lower body negative pressure (LBNP) and other countermeasures, could minimize the deconditioning of the cardiovascular and muscle systems. Space motion sickness had proved to be merely an annoyance in the early phase of flight, and Soviet mission schedules were adjusted to compensate for this temporary disability. All other changes seen in space, such as red blood cell losses, seemed to be benign and to return to normal within two or three weeks postflight. The only spaceflight adaptive change that was still worrisome, from the standpoint of near-Earth missions of this length, was the apparently progressive loss of calcium from bone.

The second generation space stations, beginning with Salyut 6, allowed longer periods of occupation. A system for regenerating water supplied crew members with wash water, and a shower was now installed. The station was fully outfitted to support what was one of its major objectives: testing the limits of human endurance of space flight. Five long-duration primary crews carried out missions to Salyut 6 lasting 96, 140, 175, 185, and 75 days. Each of the prime crews was periodically visited by short-term crews who conducted experiments separately and jointly. Often, the visiting crews studied the acute phase of adaptation to microgravity; they also served as experimental controls to the prime crews. A comprehensive program of psychological support was implemented, emphasizing frequent, varied, and highly diverting contact with a wide range of people on the ground, as well as onboard entertainment. The sleep/work schedule was carefully designed and adjusted by space psychologists on the ground.

Salyut 6 crews continued the biomedical investigation carried out by their predecessors in space. They also conducted an extensive and increasingly sophisticated series of biological experiments utilizing plants and animals, fish, and insects. Especially interesting were those experiments in which "space greenhouses" were maintained. These were small-scale ecosystems that permitted study of the interactions of various biological organisms and systems in the microgravity environment. They included many types of plants, growing on a variety of nutrient-rich substrates. These experiments, still continuing, are directed at the development of biologically regenerable life support systems that can recycle human wastes and carbon dioxide, producing oxygen, potable water, and food.

In 1982, Salyut 7 was placed in orbit. Biomedical research continued along established lines in this station, which was itself closely similar to Salyut 6. Extension of human stay-time in space was still clearly the aim, and the first crew aboard set a new duration record of 211 days, performing hundreds of experiments. A visiting Soviet-French crew performed cardiovascular studies utilizing a French-made echocardiograph device, "Echograf". A subsequent prime crew, in 1983, set a new EVA record with virtually back-to-back spacewalks approximately three hours each.

### SUPPORTING BIOLOGICAL RESEARCH

Even before the first space flights, the Soviet piloted space program had been supported by an extremely active and diverse program of biomedical research, including both human and animal studies, as well as experiments on plants, tissues, cells, and microbes. Not only are experiments carried out onboard the space stations, but control experiments are conducted on the ground. These are often extensive and long-lasting, such as those in which human subjects are subjected to many months of bedrest; in comparable biological studies, rats and other animals are immobilized by various means to examine the effects of reduced activity, or "hypodynamia." Most impressive of all are the Soviet biosatellite missions, which may contain dozens of specimens representing several phyla of plants and animals, all monitored closely from the ground. Table 6 displays all Soviet space biological missions flown on automated spacecraft through 1983.

By the end of 1983, the Soviets had flown at least 16 dedicated biosatellites, on a schedule averaging roughly one every two years since the mid-1960s. The last biosatellite flown in this period, Cosmos 1514, represented a quantum advance in that it contained two rhesus monkeys, in addition to other animals and fish. The mission involved heavy participation by U.S. investigators; one of the monkeys was implanted with U.S.-made blood pressure and flow transducers, to support cardiovascular studies.

By means of this diverse program of medical and biological research, in space and in laboratories on Earth, Soviet space medicine specialists had demonstrated by the end of 1983 that humans can remain in space for periods of up to seven months without suffering long-term ill effects; indeed, they often return to Earth in nearly as good condition as when they left. Longer missions continue to be mounted, as described in the following chapters. However, it was clear by the end of 1983 that the Soviets were beginning to gear their space life sciences effort increasingly toward very long-term missions beyond the protective environs of Earth. Efforts to understand and counteract the adaptive changes seen in the cardiovascular, musculoskeletal, and neurovestibular systems were continuing. But research on radiation effects and countermeasures, on bioregenerable life support, and on crew psychological/sociological factors, were gaining in prominence. Representatives of the Soviet space program were increasingly making reference to plans for a piloted mission to Mars, sometime in the not-too-distant future.

TABLE 6.—SOVIET AUTOMATED MISSIONS WITH BIOLOGICAL PAYLOADS THROUGH 1983

| Mission | Date | Duration | Payload/comments |
|---|---|---|---|
| Sounding rockets (suborbital): | | | |
| 1st phase | 1951–52 | | 6 flights with 9 dogs, 3 of them flying twice. |
| 2d phase | 1952–56 | | 9 flights with 9 dogs, 6 of them flying twice. |
| 3d phase | 1956–60 | | 10 flights with 14 dogs, rabbits, mice, and rats. |
| Spacecraft: | | | |
| Sputnik 2 | 11/03/57 | 163 d | Dog "Laika" aboard; no recovery attempted. |
| Korabl Sputnik 1 | 05/15/60 | 16 mo | Carried robot only. |
| Korabl Sputnik 2 | 08/19/60 | 24 hr | Biomedical experiments on 2 dogs; carried mice, guinea pigs, rats, cells, tissue, DNA, fruit flies, plants, seeds, algae, bacteria. |
| Korabl Sputnik 3 | 12/01/60 | 24 hr | 2 dogs, insects, plants, tissue cultures; burned up on reentry. |
| Korabl Sputnik 4 | 03/09/61 | 90 min | 1 dog, mice, guinea pigs, cells, rabbit bone marrow, frog eggs and sperm, fruit flies, plants, seeds, algae, bacteria, enzymes, viruses. |
| Korabl Sputnik 5 | 03/25/61 | 90 min | Repeat of above payload and experiments. |
| Cosmos 110 | 02/27/66 | 22 d | 2 dogs, plants, seeds, yeast, algae, bacteria, microspores, blood serum, albumin. |
| Cosmos 212 | 04/14/68 | 5 d | Docked with Cosmos 213; carried tortoises, seeds. |
| Zond 5 | 09/14/68 | 7 d | Tortoises, flies, worms, plants, seeds, bacteria. Circumlunar trajectory, water recovery. |
| Zond 6 | 11/10/68 | 7 d | Unspecified biological payload. Radiation monitoring and dosimetry experiments. |
| Cosmos 368 | 10/08/70 | 6 d | Plants, seeds, yeasts, bacteria, mammalian cells. |
| Cosmos 605 | 10/31/73 | 21 d | Rats, tortoises, fruit flies, bacteria, fungi. |
| Cosmos 613 | 11/30/73 | 60 d | Long-duration test of Soyuz vehicle; carried seeds. |
| Cosmos 690 | 10/22/74 | 21 d | Rats, tortoises, flies, plants, fungi, yeasts; onboard gamma ray source ($Cs^{135}$). |
| Soyuz 20 | 11/17/75 | 90 d | Tortoises, flies, plants, seeds. Parallel experiments with Cosmos 782, comparing different microclimates. |
| Cosmos 782 | 11/25/75 | 20 d | Rats, tortoises, fish, flies, plant sprouts, seeds, tissues, and cells. Tested first onboard centrifuge. |
| Cosmos 936 | 08/03/77 | 21 d | Rats, flies, yeast, plant sprouts, seeds, and tissues; rat centrifuge. |
| Cosmos 1129 | 09/25/79 | 19 d | Rats, bird eggs, plant tissue; emphasized enzymes, radiation, muscle, bone. |
| Cosmos 1514 | 12/14/83 | 5 d | 2 rhesus monkeys, pregnant rats, fish, plants; emphasized primate cardiovascular, vestibular, musculoskeletal, developmental biology. |

Prepared by Courtland S. Lewis for CRS.

## CONCLUSION

By the end of 1983, the Soviets had learned a great deal about orbital space stations and the performance of human crews. The tens of thousands of remote sensing images obtained with spaceborne cameras and the hundreds of materials processing experiments conducted from Soyuz 6 in 1969 through the end of 1983 proved to the Soviets that space experiments could have economic potential. The significant repairs conducted by crews on Salyut 5, 6 and 7 to enable the continued functioning of those space facilities showed the value of having repairmen on board. From Vostok 1 to Salyut 7, cosmonauts had evolved from passengers to integral participants in spaceflight.

By extending the duration of spaceflight, the Soviets established a basis for assessing the risks of performing even longer flights, perhaps to other planets. They learned about the psychological as well as physiological hurdles that must be overcome. They also discovered the logistical constraints that would be encountered in providing a crew with the consumables needed for a trip that could take 1.5 to 2 years. Frequent resupply missions with Progress will not be possible on an interplanetary voyage. The types of supplies, repair parts, tools, and so forth that will have to be taken along on a long journey away from Earth are better understood because of the Soviet space station missions. Although they were not able to send people to the Moon before the United States, and it must have been a bitter blow to them at the time, their "low-tech," plodding approach may appear more logical in a historical context than the "high-tech," but stop-and-go approach of the United States. While many talk today about the virtues of sending a joint U.S./Soviet crew to Mars instead of mounting a national effort, the Soviets are further ahead in understanding what would have to be done to undertake a piloted mission to Mars. If the decision were made to make the first flight a national expedition, the Soviets are now in a better position than the United States to accomplish such a goal from the viewpoint of experience.[15]

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[15] It should be stressed, however, that the United States remains the leader in space technology, another important ingredient in attempting to send crews to Mars.

# CHAPTER 2—SALYUT 7: 1984-1986

Activities that took place on Salyut 7 during 1982 and 1983 have already been reviewed. This chapter details the operational and experimental activities of the main crews that occupied the space station during 1984 and 1985, together with the visiting crews in those years and the Soyuz T-15 visit in 1986. These were very active years for Salyut 7 that included major repair work, the first crew rotation, and a vast expansion of the use of extravehicular activity by Soviet crews. At the end of the Soyuz T-15 visit to Salyut 7 in 1986, the Soviets boosted it (using Cosmos 1686 to which it is still attached) into a high orbit (approximately 500 kilometers circular) and announced that they would monitor the station to see how its systems degrade over time. They left open the possibility of a return "rendezvous" mission in a few years to retrieve samples from the space station itself for examination on Earth. For more information on the status of Salyut 7, see the section entitled "Soyuz T-15" below. Since the experiments were conducted by many different crews, they are consolidated in the first section. Information on individual crew operations for each of the crews that occupied Salyut 7 from 1984 to 1986 follows.

## EXPERIMENTS

It is interesting that so many experiments were able to be conducted aboard Salyut 7 from 1984 to 1986 since the crews spent so much of their time on operational tasks. Although they were on the space station for 237 days, for example, the Soyuz T-10/T-11 crew often found itself performing EVAs (a total of six); unloading Progress cargo craft (five were launched during their mission); or working with the two visiting crews (Soyuz T-11/10 and Soyuz 12). The situation was not much better for the 1985 Soyuz T-13 and T-14 crews. The T-13 crew spent most of its time reviving the space station after a major electrical failure, and the productivity of the T-14 crew was hampered by the illness of its commander which ultimately led to an emergency termination of the mission. The final mission to Salyut 7, Soyuz T-15, simply "dropped over" from the new space station Mir to complete activities that were not finished by the T-14 crew. Among their tasks was performing two more EVAs.

Every task on board the space station is, in a sense, an experiment. The EVAs are important for the future of the Soviet space program. Medical examinations are required to determine how humans withstand weightlessness, even the rest days (every Saturday and Sunday) are important to psychological adaptation to long duration spaceflight. All of these activities, however, reduce the time available to conduct what are traditionally thought of as "experiments" in materials processing, remote sensing, atmospheric and astronomy studies. The impression in the West that the Soviet crews had been able to accumulate hundreds of hours performing these more traditional experiments is somewhat overstated, although they certainly have considerable more experience than U.S. crews.

The cosmonauts "work" eight hours a day, five days a week, on average. The rest of their time is spent on routine chores: exercising (two or two and a half hours a day is required), eating, sleeping, cleaning, communicating with Flight Control, and so forth. Everything else—unloading cargo ships, performing EVAs, doing medical checks, and conducting "experiments"—must be accomplished essentially in a 40 hour work week. This does not leave as much time for materials processing and other experiments as might be presumed.

Despite the heavy load of operational and routine assignments they had, crews that visited Salyut 7 from 1984 to 1986 managed to accomplish a great deal. The 237-day Soyuz T-10/T-11 crew performed more than 550 scientific experiments, took 4,400 photographs with the MKF-6M camera and another 1,640 with the KATE-140. At the end of the Soyuz T-14 mission, which was both the first transfer of crew operations (from Soyuz T-13) and the first mission terminated early because of illness, it was reported that the crew had completed 400 scientific experiments and photographed some 16 million square kilometers. It was not clear if this was just for the Soyuz T-14 part of the mission, or the combined Soyuz T-13/T-14 time in space. No specific numbers were given for the T-15 crew that spent 50 days on Salyut 7 in 1986 sandwiched between activities on the new space station Mir, but they did perform at least a few experiments.

In total, these crews to Salyut 7 performed a total of 10 EVAs. Most of these (six by the T-10/T-11 crew and one by the T-13 crew) were operational, not experimental, and are discussed under the specific mission rather than here. Only those that were primarily experimental (the T-12 EVA for testing a device for welding and spray coating, and the two by the T-15 crew for space construction and welding) are described in detail in this section.

## MATERIALS PROCESSING AND OTHER MATERIALS SCIENCE

Many of the experiments on Salyut 7 from 1984-1986 were continuations of those performed earlier on the space station, or were similar except that they used new versions of the equipment. Included were the Isparitel (Vaporizer) experiments for spray coating materials, the Tavria electrophoresis experiment and its successor EFU-Robot, electrophotograph experiments conducted in the airlock, and the microdeformator experiments on the outside of the space station. New experiments, such as the test of the URI device for welding and spray coating during EVA, were also primarily evolutionary designs of equipment (URI was an advanced version of Isparitel, for example). The Gel experiments were the only ones in this category that did not have readily apparent predecessors on earlier flights.

*Isparitel-M (Spray Coating)*

The Isparitel device used by the Soyuz T-10/T-11 and subsequent crews was an improved model of the one used on earlier flights, and designated Isparitel-M. Described as an electron beam gun, it could shoot electrons at a refractory crucible filled with silver, copper, gold or a copper-silver alloy. The metal vaporizes and settles on a metal or glass plate, forming a mirror-like coating. The "M" stood for modernized and the new model could deposit coatings as thick as tenths of a millimeter, its capacity was larger, and its vaporization speed higher. It could perform eight different kinds of work simultaneously involving the deposition of coatings on a stationary substrate or a tape made of polymer film and drawn over the stream of vapors, and the vaporization of plastics, particularly fluoroplastic, and alloys. A March 13, 1984 report stated that the Isparitel-M could be converted into a "pistol" that could work like a hand paint sprayer, and "one variant of such a 'pistol' has already been perfected."[1] This may have been a reference to the URI device used by Dzhanibekov and Savitskaya on their EVA (see below).

V. Lapchinskiy, head of a laboratory at the Institute of Electric Welding, commented that Isparitel-M was a new device more than a modernized unit, and already was "almost semi-industrial."[2] It weighed 34 kilograms and consisted of two units: the operating unit, including several replaceable crucibles; and an information-and- measuring complex, allowing the monitoring of the vaporization process as well as programming the necessary operating parameters automatically. The new device could handle a broader range of substances, including silver, gold, copper, a copper-silver alloy, a number of other metals and alloys, and nonmetallic materials such as plastics. Lapchinsky commented that he and his colleagues thought several square meters could be covered with a thin metallic film, but the immediate task was to work out optimal routines and test an alloy, not to achieve maximum speed.[3] He concluded that the work with Isparitel-M could pave the way for reconditioning spacecraft coatings in orbit.

The Soyuz T-11/T-10 Soviet/Indian crew conducted Isparitel experiments called "pereokhlazhdeniye" (supercooling) to study supercooling in the solidification of molten metals and investigate possibilities of obtaining special forms of metallic materials "glassy alloys" in zero gravity. For these experiments, an auxiliary unit was built by Soviet specialists, while the Indians prepared the silver-germanium alloy specimens that were used.[4] Press reports explained that on Earth, supercooling had to be done by melting one side of the alloy with a laser while the other side was cooled with liquid helium, and that the product of "this complex and costly process is a metal that holds up well to effects of radiation" and could be used in the walls of nuclear reactors, and in turbine blades of airplane engines, for example. For the latter application, it was noted that "a 100 degree increase in the temperature tolerance of turbine blades permits a 30 percent reduction in fuel consumption." Thus, this experiment was said to represent an initial step toward the industrial production of superdurable materials capable of withstanding radiation and chemical stresses.[5] An Indian press report on April 9, 1984 indicated that the furnace was not working well, but that the cosmonauts eventually overcame the difficulty during the seven-day visit to Salyut 7.[6]

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[1] Sotsialisticheskaya Industriya, March 13, 1984, p. 4

[2] Rabochaya gazeta, March 14, 1984.

[3] Rabochaya gazeta, March 14, 1984; Pravda Ukrainy, March 27, 1984.

[4] Komsomolskaya Pravda, April 8, 1984.

### *Welding, Spray Coating and Space Construction on EVA*

During the Soyuz T-12 visiting mission, cosmonauts Dzhanibekov and Savitskaya performed a series of welding and spray coating experiments while on EVA using a tool that could also be used for welding, cutting and soldering. A derivative of the Isparitel-M, an improved version was subsequently used by the Soyuz T-15 crew. Called URI, it was developed by V. Lapchinskiy, who had also worked on the Isparitel-M. The URI was based on the Isparitel's electron beam gun which weighs 1.5 kg (Isparitel itself weighs 30 kg). Before taking it into space, it was tested in a zero gravity airplane flight.

The URI included converters and a control system that could be fastened with clamps to the handrails on the outside of the station and Lapchinskiy described it as looking like a hand held camera with two lens barrels: one for cutting, welding and soldering metals; the other for applying coatings. It fit into a box half a meter square. On one side of the unit were four folding, board-type specimen holders; each could hold six specimens, two of stainless steel and four of titanium. The electron beam was focussed with the aid of a lens onto the specimens which then could be cut, welded or soldered. The other barrel was for spray coating specimens with silver and had a built-in crucible for melting the silver.[7]

Some of the problems that had to be overcome before using the URI were described by Vladimir Nikitskiy, described as an organizer of the welding experiment. The station's onboard voltage had to be converted into voltage sufficient for the electron gun; methods had to be developed for controlling the high temperature generated by the gun and protecting the space suits; and the size and weight of the gun had to be minimized.[8] The temperature of the URI was monitored by a pistol shaped non-contact infrared thermometer.

The first experiments were done by Savitskaya and Dzhanibekov in 1984. Their work was monitored via television. First, Savitskaya cut a titanium sample 0.5 millimeter (mm) thick, then she welded samples 1 mm thick, soldered, and then sprayed a thin layer of silver on anodized aluminum.[9] The thickness of the samples varied. Dzhanibekov also performed experiments, and in total, six welding experiments were done, two with titanium and four with stainless steel. Six cutting experiments were performed, three of titanium and three of stainless steel. There were also six soldering experiments using tin and lead solder, and two experiments in applying a silver coating to anodized aluminum. All were returned to Earth for study.

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[5] Trud, April 11, 1984.

[6] Delhi Domestic Service, 0240 GMT, April 9, 1984.

[7] Sotsialisticheskaya Industriya, July 27, 1984; Izvestiya, July 27, 1984.

[8] Komsomolskaya Pravda, July 31, 1984, p. 2.

[9] Moscow Domestic Service, 0655 GMT, August 10, 1984.

During a post-flight press conference, Savitskaya concluded that "At least as far as the outer appearance goes, the welded joints obtained in space are in no way inferior to good industrial samples on Earth. Good samples of applied silver coating were also obtained." Dzhanibekov discussed the ramifications for future space activities, noting that the samples were very diverse:

> . . . for example, a nut and bolt fastening. There is a thread there and if they are done to some geometrical rule, with some sort of margin, then there are materials which in a vacuum in space, rapidly coalesce and form an absolutely firm connection; the results cannot be undone by any means, as diffusion processes take place and for certain materials these are very active. Yet other pairs of metals are completely unaffected, so these kinds of fastenings can be used there for such ordinary tasks as are encountered on Earth. [The instrument] will be used in the future to construct very large and complex structures which simply cannot be raised from the Earth. . . In the future, I hope that we will be able to weld and clad structures, and assemble various specific sections. Eventually this will enable us to have the possibility of thinking about the construction of cities in space orbit, real cities.[10]

Academician B. Paton reported on the work in November 1984 and left some question as to how successful the experiment had been. He commented that in studying the results:

> . . . one must not disregard the anxiety of persons who were working in open space, and the setting, which was entirely different from that of an earth pressure chamber, as well as the very fact that such welding was being performed in orbit for the first time. Therefore one must give a very high appraisal of the specimens of metal joined by the method of hand electron-beam welding in space, despite the fact that certain defects are present. There is no doubt that in upcoming missions, it will be possible to begin performing practical work using this method. It is not a simple matter to burn through a thin sheet of metal in zero gravity. In these conditions, the cutting of plates requires good focussing of the electron beam, steady movement of the tool, and in some cases returning to sectors that have been cut poorly. It is encouraging that the cosmonauts handled the cutting of metal well. The soldering process proved to be more complex. But even here the cosmonauts managed to obtain several good specimens. The spraying of coatings did not present special difficulties for the cosmonauts, and the specimens obtained in orbit, at least externally, can satisfy the requirements of the most rigid standards.[11]

The Soyuz T-15 crew performed additional experiments of this nature when they were onboard Salyut 7 in 1986. During EVA, they conducted additional welding experiments using an improved version of the URI based on recommendations by Dzhanibekov and Savitskaya that made it easier to operate.[12]

The T-15 crew also performed a space construction experiment with a hinged metal lattice work girder. The intent of the experiment was to determine how to fold and refold the girder, and to test its strength. Two instruments were mounted on the girder the second time it was extended: the "Fon" (Background) device for measuring the atmosphere around the structure, and an instrument to monitor the vibrations of the frame. Fon was described as a magnetic discharge converter weighing 3 kg and capable of distinguishing between molecules that had escaped from the Earth's upper atmosphere and those created in the vicinity of the space station.[13] Solovyev commented that this was the first time the station's atmosphere was studied in real time.[14] Kizim "climbed" the frame like a stepladder, commenting that it rocked, but was firm.[15]

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[10] Moscow Domestic Service, 0655 GMT, August 10, 1984.

[11] Pravda, November 5, 1984, p. 3..

[12] Pravda, August 16, 1986, p. 3.

[13] Pravda, June 1 1986, p. 6.

### *Tamping and Svetoblok-T Gel Experiments*

The Soyuz T–12 crew conducted the *Tamping* experiment related to developing sealing materials for use in oil and gas wells. As described by Cosmonaut Volk at a post-flight press conference, the aim of the experiment was to clarify the "detailed mechanism of the initial stage of the formation of gels in colloid suspensions or, to put it simply, the initial stage of hardening of cement under similar linking solutions." Using a device developed by Moscow's Gubkin Institute of the Petrochemical and Gas Industry, three samples were prepared in space: water, dicalcium silicate, and corundum quartz; water, tricalcium silicate, and corundum quartz; and water, dicalcium silicate, quartz, and liquid glass. They were prepared over 10 days, hardened on board the station, and returned to Earth. According to Volk, "today, one can only say that the kinetics of hardening of such suspensions in space and on Earth differ substantially."[16]

Cosmos 1669 brought the *Svetoblok-T* experiment for forming a "polyacrylamide gel by means of photoinitiation."[17] It was described as creating a "molecular sieve" with pores of different sizes for use on Earth to separate biologically pure substances by electrophoresis.[18]

### *Korund, Magma-F, and Kristillizator (Materials Processing)*

In November, 1985, after Cosmos 1686 had docked and its scientific equipment checked out, the Soviets mentioned three new materials processing devices. It can be assumed they were brought to Salyut 7 on Cosmos 1686. They included Korund and Magma-F, as well as Kristillizator. The latter was said to have improvements over previous devices in areas such as the precision of measurements and temperature control, range of rates of movement of specimens, data-recording capacity, and control of experiments. It was developed jointly with Czechoslovakia.[19] Vasyutin's illness, which terminated the Soyuz T–14 mission prematurely, prevented the crew from working with this equipment extensively.

The T–15 crew worked with Kristillizator briefly when they visited Salyut 7 in 1986. At that time it was described as being used for studies of mass and heat transfer (apparently similar to the Pion experiments) and of crystallization in weightlessness.[20] Korund and Kristillizator experiments were conducted on Mir, but apparently with new equipment. No further mention of Magma-F was made.

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[14] Solovyev, V.A. Man in Space. Paper presented to the 38th Congress of the International Astronautical Federation, October 10–17, 1987, Brighton, England. IAF–87–77, p. 4.

[15] Moscow Domestic Service, 0800 GMT, May 31, 1986.

[16] Moscow Domestic Service, 0655 GMT, August 10, 1984.

[17] Izvestiya, August 7, 1985, p. 1.

[18] Komsomolskaya Pravda, September 21, 1985, p. 2.

[19] Pravda, November 12, 1985, p. 3.

[20] Izvestiya, June 18, 1986, p. 1.

*Tavriya (Electrophoresis)*

Electrophoresis experiments using the Tavriya device were conducted by the Soyuz T-12 crew throughout their stay. Press reports noted that they were a follow on to earlier experiments that had produced samples 15-20 times more pure than on Earth, and that the Soyuz T-12 crew was creating more of the influenza vaccine that had been produced in 1983 by the Soyuz T-9 crew.[21] The T-12 experiments were conducted by Savitskaya, who described them in a post-flight press conference. They were done for several scientific-research organizations:

> . . . the Shimyakin Institute of Bioorganic Chemistry, which asked us to refine two batches of human interferon synthesized by Soviet scientists under the leadership of Academician Ovchinnikov by means of genetic engineering. A number of institutes and the Ministry of Health asked us to refine three batches of influenza preparations. Institutes engaged in increasing agricultural productivity asked us to isolate effective organisms that produce a food antibiotic for animals which is both a medicine and a growth stimulant for animals. At the request of the Kiev scientific institutes, which are engaged in the creation of new medicines and preparations, we refined a preparation made from human blood protein.[22]

Sixty ampules were obtained and returned to Earth. The Pasteur Scientific Institute of Epidemiology and Microbiology in Leningrad was also identified as using results of this work.[23]

The status of moving into industrial production with space electrophoresis was assessed differently by various Soviet scientists. Candidate of Medical Sciences A. Lepskiy was quoted as saying that results have shown it "possible and economically advantageous to obtain in space superpure biological preparations in quantities sufficient for practical employment in public heath and agriculture."[24] Another report stated that "The Tavria installation incorporates some new systems and equipment which are essentially a prototype of future semi-automatic installations for space biotechnology,"[25] while Savitskaya termed it "an experimental industrial unit."[26] Cosmonaut and doctor of technical sciences Konstantin Feoktistov asserted that space station research was "promoting the creation of a space industry," proceeding "fairly intensively" and in "a number of instances passing from the trial and experimental stage to semi-industrial production." He added, however, "This applies specifically to the growing of high-quality monocrystals on board the Salyut station,"[27] rather than to electrophoresis. Academician Oleg Gazenko, head of the Institute of Biomedical Problems, gave a cautious assessment, saying space electrophoresis "is still in the experimental stage."[28]

In 1984, the *Genom* experiment was conducted. It was described as an electrophoresis experiment that separated fragments of DNA molecules to study their links. This is difficult to do on Earth because of thermal convection. Samples were taken of nearly 700

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[21] Izvestiya, July 22, 1884.
[22] Moscow Domestic Service, 0655 GMT, August 10, 1984.
[23] Leningradskaya Pravda, Juhy 28, 1984.
[24] Izvestiya, July 22, 1884.
[25] TASS, 1130 GMT, July 24, 1984.
[26] Moscow Domestic Service, 0655 GMT, August 10, 1984.
[27] TASS, 1435 GMT, October 3, 1984.
[28] Moscow Domestic Service, 0655 GMT, August 10, 1984.

DNA fractions for subsequent analysis. Ultraviolet photography was used to follow the course of the experiments.[29]

### *EFU-Robot (Electrophoresis)*

The Soyuz T-14 crew delivered a new automatic electrophoresis installation called *EFU-Robot* that was a successor to the Tavriya instrument.[30] Developed by the Institute for Bioorganic Chemistry, it could be programmed by a crew member to select samples of substances purified in the course of experiments and automatically transfer the samples from the unit's working chamber to ampules, using syringes. Albert Krashenyuk, head of a department at the Leningrad Scientific Research Institute of Vaccines and Serums, said that the experiments would yield immune serums and that one such serum had already been used to obtain a fundamentally new preparation for diagnosing influenza with high accuracy.[31]

The EFU-Robot device was transferred from Salyut 7 to Mir by the Soyuz T-15 crew.

### *Electrophotograph and Microdeformator (Deterioration of Materials in Space)*

The *Electrophotograph* experiments continued in 1984 and 1985. Aleksandr Kravtsov, a science associate of the Ukrainian Academy of Sciences Institute of Physics, discussed earlier experiments conducted by the Soyuz T-9 crew in 1983. Those experiments showed that the breakdown of materials exposed in space proceeds at an uneven rate. The Soyuz T-12 crew brought "not only model materials but also structural ones and individual components of these materials." Highly sensitive black and white film and color film were used to record changes in the structure of the materials while exposed to space conditions in an airlock, and it was noted that previous experiments had proven that color film with a layered structure provided the most information.[32]

Procedural changes were made in the conduct of these experiments starting with the Soyuz T-10/T-11 crew. Specimens were exposed for longer periods of time,[33] and, based on Kizim's recommendation, the station was rotated so the airlock pointed toward the Sun during the experiments, reducing the time needed to ensure the requisite temperature conditions in the airlock from 6 hours to a few minutes. A press report stated that Kizim was able to remove samples only 10 minutes after closing the hatch, while Kravtsov commented that the chamber had been opened for 40 hours during the experiment.[34]

An experiment called *Torsion* was conducted in May 1984 to study the influence of space conditions on structural materials. The report stated that an instrument in the station's airlock was used, and this may well have been part of the Electrophotograph series. It was described as determining changes in the physical-mechanical characteristic of materials "by means of evaluating parameters of free damped vibrations that were periodically transmitted to the specimen".[35]

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[29] TASS, 1414 GMT, August 24, 1984.
[30] Komsomolskaya Pravda, September 21, 1985, p. 2.
[31] Leningradskaya Pravda, October 13, 1985, p. 2.
[32] Izvestiya, July 26, 1984.
[33] TASS, 1130 GMT, July 24, 1984.
[34] Pravda, July 26, 1984.

While on board Salyut 7 in 1986, the Soyuz T-15 crew installed the *microdeformator* experiment which was designed to operate "permanently there in space with samples which it will stretch, squeeze, and so on; in other words it will test the properties of the metal, its strength characteristics."[36] The microdeformator was described as a small tensile-stress machine for testing specimens of an aluminum-magnesium alloy. "Changes in the specimens to the point of creep are measured."[37] In an August article in Pravda, B. Paton and Yu. Semenov commented that the results of the microdeformator experiment would permit development of a mathematical model that would forecast how materials respond in space over a 25-year period.[38]

### *Other*

Occasionally, Soviet press reports mentioned experiments that were never further described. In September 1985, for example, a press report referred to the *Birtuza* and *Analiz* devices for studying the process of growing crystals.[39] In October 1985, the first mention in several years was made of use of the Pion device for studying heat and mass transfer, especially into the possibility of thermocapillary flow control by means of temperature field variables.[40]

The Soyuz T-15 crew in 1986 retrieved specimens left by previous crews on the outside of Salyut 7. One experiment was called *Spiral* for studying the effects of space on cable products and materials. Another, called *Istok* was to determine changes in the characteristics of threaded connectors such as nuts and bolts. A third, called *Resurs*, assessed the effects of space conditions on structural metal materials.[41]

## MEDICAL/BIOLOGICAL EXPERIMENTS

Chapter 4 provides details on the physiological and psychological aspects of long duration spaceflight based on information gleaned in the Soviet space program, as well as other information about biological aspects of the space station missions. This section will only review the types of experiments conducted, not their results.

From a medical perspective, the most interesting mission during the Salyut 7 era was the 1984 Soyuz T-10/T-11 crew that included a physician, Oleg Atkov. This was only the second time a medical doctor was included on a Soviet crew (the first time was Voskhod 1 in 1964).[42]

The virtues of having a physician aboard were extolled by doctors on the ground who pointed out, for example, that for first time blood samples could be taken from veins as well as fingers.[43] They were also able to use maximum loads for the Chibis negative-pressure suit, which could be dangerous if no doctor was aboard to monitor the effect on the cosmonauts. The desire to use greater loads was prompted by the need to discover the reserve capacities of the body.[44]

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[35] Krasnaya Zvezda, May 27, 1984, p. 1.

[36] Moscow Domestic Service, 0800 GMT, May 31, 1986.

[37] Pravda, June 1, 1986, p. 6.

[38] Pravda, August 16, 1986, p. 3.

[39] Moskovskaya Pravda, September 4, 1985, p. 1.

[40] TASS, 1557 GMT, October 15, 1985.

[41] Trud, May 29, 1986, p. 3.

[42] Vasiliy Lazarev, who flew on Soyuz 12 in 1973, had a degree in aviation medicine, but had turned to piloting activities in 1954. Since he had not been a practicing doctor for almost 20 years before his flight, he is not counted as a physician-cosmonaut in this report.

[43] Meditsinskaya gazeta, April 11, 1984.

A.I. Grigoriev, deputy director of Institute of Biomedical Problems, noted that it was also possible to lengthen the intervals between days on which comprehensive medical exams were performed, and to conduct medical research on practically any day. He said that cardiovascular studies "take up a larger portion of the flight program than during any previous mission. For the first time in space, the method of load tests has been employed to evaluate calcium metabolism, using the Biokhim instrument. Studies of the level of immunoglobulins in blood serum are expected to aid research of changes in immunologic reactivity that have been noted in participants in certain prolonged space missions."[45] The deputy flight director of the 237 day Soyuz T-10/T-11 mission, V. Blagov, added that "The current mission is the first one in which a specialist is to draw conclusions regarding the quality of means of personal hygiene and certain parts of the station's everyday living conveniences."[46]

Despite the several very long duration Soviet flights, many unsolved problems remained, including the effects of cosmic radiation, nervous and emotional stress caused by working on orbit, and motion sickness.[47] Therefore many medical experiments were conducted throughout all the missions from 1984 to 1986, but especially the Soyuz T-10/T-11 mission. Cosmonaut Feoktistov noted after the mission that: "Medical research and control on 33 parameters were carried out for 87 out of the 237 days. Some 317 medical measurements gathered data on the cardiovascular system, the vestibular apparatus, metabolism, vision, olfaction, circulatory and immunity systems, psychophysiological functions, anthropometry, and the sanitary condition of the dwelling."[48]

Cosmonaut Volk commented at his Soyuz T-12 post-flight press conference that one reason for all the medical experiments is to be able to broaden the base from which cosmonauts can be chosen "to expand the list of professions" that can be represented on spaceflights.[49]

### *Exercise*

Changes were made in the daily exercise regimen for the T-10/T-11 crew. It was more vigorous, but could be accomplished in "only" two hours. It was noted that the change was permissible because a physician was aboard to monitor the cosmonauts. Called *Sport*, it used new physical conditioning regimens for the exercycle and running track. Oleg Gazenko, director of the Institute for Biomedical Problems, stated that the new exercises consumed less time, but were more intensive and strenuous. Atkov was reported to be instrumental in evaluating the effectiveness of the new regimen.[50] Shortening the length of time for exercise is important to increasing the productivity of the cosmonauts.

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[44] Izvestiya, March 3, 1984.
[45] Meditsinskaya Gazeta, August 8, 1984.
[46] Trud, February 13, 1984.
[47] Meditsinskaya gazeta, March 2, 1984.
[48] Aerospace America, May 1985, p. 97.
[49] Moscow Domestic Service, 0655 GMT, August 10, 1984.

On the Soyuz T-12 flight, Cosmonaut Volk did not exercise as part of an experiment aimed at broadening scientists' understanding of human reaction to spaceflight. Press reports said that his body was therefore functioning in "more difficult conditions" and that he was regularly taking tablets to reduce motion sickness symptoms. Atkov monitored him.[51]

### *Cardiology*

Atkov was a cardiologist, so studies of the heart were quite prominent during the Soyuz T-10/T-11 mission. He helped design a special echocardiograph that weighed only 2.5 kilograms (kg), compared to 50-60 kg for those used on Earth.[52]

The *Ballisto* experiment evaluated the force of heart contractions and the coordination of the functioning of the heart's right and left sections using ballistocardiography. The data were expected to broaden knowledge about changes in the heart's hemodynamics and function in weightlessness. Ballistocardiograms were recorded using a piezoelectric accelerometer attached to three different parts of the body in succession. Three-dimensional pictures of the distribution of forces of heart contractions were obtained.[53]

*Vektor* was a joint Soviet/Indian experiment to gain more information on the phase structure of the cardiac cycle and on changes in the filling of the ventricles during various periods of cardiac activity, evaluating compensatory-adaptive reactions of the circulatory system using a number of new electrocardiographic and kinetocardiographic methods. A portable vectorcardiograph was developed by the Indian "KHAL" firm that not only recorded the heart's electrical activity on tape, but also vibrations of the chest caused by heartbeats.[54]

### *Motion Sickness*

Studies to determine the causes of space motion sickness (also known as space adaptation syndrome) in some cosmonauts when they first arrive in space continued during all the flights from 1984-1986 on Salyut 7. As noted by Igor Komordin, chief of the Soviet Ministry of Health Administration of Space Biology and Medicine, at the beginning of the 237 day mission "[t]he majority of people who have been in space have suffered to one degree or another from motion sickness."[55] Still, the causes of, and effective remedies to, this problem have eluded physicians.

The *Optokinez* experiment studied oculomotor function and vestibular-visual interactions by observing the pupils and how they respond to certain light stimuli. Early in the T-10/T-11 mission, Solovyev was tested by putting his head inside a large square box while Atkov switched on a revolving drum which caused streaks of light to run rapidly through the inside of the box. Solovyev followed these streaks with his eyes. Later, it was reported that the cosmonauts followed the movement of visual stimuli on the screen of a videotape recorder. Electrooculograms, electrocardiograms and pneumograms were recorded during the experiment.[56] Malyshev and Sharma did this experiment when their Soyuz T-11 crew visited the T-10 crew.[57]

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[50] Meditsinskaya gazeta, April 1, 1984 and May 18, 1984.
[51] Izvestiya, July 22, 1984.
[52] Izvestiya, August 24, 1984.
[53] Sotsialisticheskaya Industriya, April 10, 1984; Meditsinskaya Gazeta, April 13, 1984.
[54] Sotsialisticheskaya Industriya, April 10, 1984.
[55] Izvestiya, March 3, 1984, p. 3.

Sharma, the Indian cosmonaut, also performed *Yoga* exercises to study changes in biomechanics of motion and impairments of coordination in space. Instruments called "Miokomp" and "Briz" recorded certain parameters of motor activity of groups of muscles during the exercises. Sharma did the exercises for one hour every day for six weeks prior to flight, and continued to do them on the space station, strapped into position on the treadmill.[58] The data were later compared with Sharma's two Soviet colleagues who served as controls.[59]

The T-11/T-10 crew members used the *Pnevmatik* and *Braslet* devices, special cuffs of different designs, to slow the flow of blood from the lower half of the body so the rush of blood to their heads was not as intensive. The *Pnevmatik* test was also performed with the with T-12 crew and Cosmonaut Volk commented in a postflight press conference that the device created "a deposition of blood in the legs" which hampered redistribution of blood to the upper half of the body. He reported that Savitskaya had done this on her first flight (in 1982) and that it also had been done by other cosmonauts and "showed a sufficiently effective preventative action." During the experiments, the crew members filled out questionnaires about their sensations, which were compared with preflight data.[60]

### *Other Medical*

The *Membrana* experiment studied the body's loss of salt in weightlessness and how to retard it. Atkov drew blood samples from Strekalov's fingers during the Soyuz T-11/T-10 mission and injected it into 30 sealed ampules containing biocomponents. Strekalov returned them to Earth for analysis.[61] *Gluykometer* was a biochemical experiment for studying features of carbohydrate metabolism.[62]

Atkov made *sanitary-and-hygienic* studies to find out, for example, how much dust there was and where it comes from, whether the fans create drafts that could cause a cold, if the work areas were illuminated properly, whether clothing and footwear were comfortable, and if the personal hygiene facilities were effective. "These are far from minor details and these factors at times determine both the mood of the cosmonauts, their feelings and to some degree the success of carrying out the flight program."[63]

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[56] Trud, February 13, 1984; Meditsinskaya Gazeta, April 13, 1984.

[57] TASS, 1127 GMT, April 5, 1984.

[58] Meditsinskaya gazeta, April 6, 1984; Sotsialisticheskaya Industriya, April 7, 1984; Izvestiya, April 7, 1984.

*ERR14*[59] Pravda, April 7, 1984.

[60] Moscow Domestic Service, 0655 GMT, August 10, 1984.

[61] Krasnaya Zvezda, April 10, 1984; Meditsinskaya Gazeta, April 13, 1984.

[62] Pravda, March 24, 1984.

[63] Izvestiya, February 18, 1984.

He also performed a number of *otorhinolaryngologic* exams and studies of the fundus of the eye which yielded data on dynamics of blood supply of the rhinopharynx, the tympanic membrane and the eye during various periods of adaptation to weightlessness.[64]

After the mission, Atkov commented on the *psychological* aspects of the mission following queries about pre-flight concerns that the dynamics of a three person crew might create "two against one" disputes. Atkov said that no problem developed because all the crew members understood that they were doing serious work whose results depended on their good relationship. He said that in those cases where a problem did occur between two members of the crew, "we would not appeal to the third member and would work out the problem independently. The third member, if he could, would try to find a compromise solution. And everything always worked out in the interests of the matter."[65]

The *Opros* (questionnaire) experiment, used initially in the Soviet/Polish spaceflight, was expanded by questions recommended by specialists in India. The experiment was described as allowing the cosmonauts to make self-assessments of the characteristics of motion in weightlessness, the features of performing familiar operations and forming new work habits, appetite and sleep habits, and interactions with other crew members. The information can be used to assess a crew member's psychological adaptation.[66]

The Soyuz T-14 crew brought the *Signal-RD* experiment which the Soviets said stood for "reflex diagnostics." The Soviet press reported that "Scientists now agree that the human body has a multitude of points that are connected with various internal organs. Acting on them with a thin needle or an electric current, it is possible to fight many ailments. And it is also possible to get an accurate diagnosis—a change in electrical resistance gives physicians valuable information on how one feels." The device was described as being the size of a telephone, and able to "examine as many things as an experienced therapeutist could."[67]

### *Biological*

While the Soyuz T-12 crew was aboard, the Soviet/French "*Citos-3*" experiment was conducted to study the effect of spaceflight on the permeability of walls of cells of microorganisms and other characteristics. Citos-3 was an improved version of previous experiments of this nature which "yielded remarkable results" that "enabled scientists to ascertain the resistance of microbes to various antibiotics." While the crew conducted the experiment in space, it was also performed on the ground for comparison purposes.[68]

In 1985, plant growth experiments resumed using equipment delivered by Cosmos 1669, apparently the *Biogravistat* apparatus which had a centrifuge for studying plants in artificial gravity. Another experiment, called *Substrat*, was designed to evaluate the effectiveness of cultivating higher plants in weightlessness.[69] Reference was also made to the *Oazis* and *Vazon* space greenhouses to study the development of high plants in weightlessness. Oasis, Vazon and Biogravistat were said to be studying pepper, onion and lettuce.[70]

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[64] Meditsinskaya Gazeta, May 18, 1984.
[65] Meditsinskaya Gazeta, April 12, 1985.
[66] Pravda, April 7, 1984.
[67] Komsomolskaya Pravda, September 21, 1985, p. 2.
[68] Pravda July 22, 1984; Sovetskaya Rossiya, July 22, 1984; Moscow Domestic Service, 0655 GMT, August 10, 1984.

The *Meduza* experiment was also carried out using samples attached to the outside of the space station on an EVA by the Soyuz T-13 crew. The experiment dealt with synthesizing components of nucleic acids.[71] It was later described as studying the long term effect of zero gravity and radiation on biopolymers, and was retrieved by the Soyuz T-15 crew.[72]

In July, 1987, a report was made on an experiment conducted by the Soyuz T-13 crew on Salyut 7 for growing cotton seeds. The Soviet press reported that the T-13 crew brought back to Earth 20 seedlings that had been planted in space; they were then replanted on Earth and a second generation of plants was now appearing. The report went on to say that the first two experiments for growing seeds in orbit had been unsuccessful, and the crew this time had "literally breathed on the seedlings" and devised a special watering procedure. The first green leaves appeared while the mission was still in progress, so cotton became the third crop (after wheat and peas) to sprout on a spaceship. According to the report "interesting changes in fiber lengths are now being observed in one of the plants"[73] and they plan to continue the studies in the future.

### REMOTE SENSING OF THE EARTH AND ITS OCEANS

As with previous space station missions, remote sensing continued to receive considerable attention on Salyut 7 from 1984 to 1986. By the end of the 237 day Soyuz T-10/T-11 mission, 4,400 photographs had been taken with the MKF-6M six-band camera, and another 1,640 with the KATE-140 topographical camera. Among the practical benefits of remote sensing was a report that on April 8, the crew radioed a warning to ground control about the forest fire they had spotted in Burma.[74] After the Soyuz T-14 mission, it was stated that 16 million square kilometers had been photographed, and although no specific numbers were given, the Soyuz T-15 crew also conducted remote sensing observations.

Virtually all areas of the globe passing underneath the space station were studied. The space station's orbit took it over all parts of the world between 51.6 degrees north and 51.6 degrees south latitude. In light of the vast areas that were covered, only special programs will be described here. The major observations were done by the MKF-6M camera built by East Germany, and the KATE-140 topographical camera, in addition to visual observations by the crew.

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[69] Ivanova, T. N., and P. T. Kostov. Prospects for the Use of the Higher Plants in Space Flight—Experiment "Substrat." Presented at the 37th Congress of the International Astronautical Federation, Oct. 4-11, 1986, Innsbruck, Austria. IAF/IAA-86-374.

[70] TASS, 0934 GMT, July 23, 1985; Izvestiya, August 28, 1985, p. 1; Moscow Domestic Service, 0500 GMT, October 1, 1985; TASS, 1114 GMT, October 18, 1985; TASS, 1337 GMT, October 22, 1985.

[71] TASS, 1052 GMT, August 9, 1985.

[72] Trud, May 29, 1986, p. 3.

[73] Pravda Vostoka, July 22, 1987, p. 3.

[74] TASS, 1025 GMT, April 8, 1984.

Soviet press reports continued to herald the value of space remote sensing, noting, for example, that "Photographs from space have already helped discover a number of deposits of oil, gas, coal, and metal ores."[75] The cosmonaut crews were trained on airplane flights and made logs containing specific assignments, methodological instructions, and maps and space photographs indicating objects to be observed. An interesting note made in *Pravda* in July 1984 said that the first and second bands on the MKF-6M have "heightened focal depth in studying the ocean floor." While it is well known that many observations are made of the ocean, the reference to studies of the ocean floor seemed new.[76]

### *Indian "Terra" Observations*

Following the tradition established with earlier crews that included representatives from other countries, during the Soviet/Indian mission a special set of Earth observations was conducted with the Indian cosmonaut. Forty percent of the Indian territory was studied using visual observations in addition to the MKF-6M and the KATE-140 cameras. Special areas of interest included: Andaman, Nicobar and Laccadive Islands (looking for oil and gas-bearing areas in shallow water); ring structures on the Indostani peninsula and blocks of forests and forest plantations in the central part of the Indostani peninsula; ice and snow cover on the Himalayas; the Indian Ocean (to identify areas of high biological productivity); the Arabian Sea; the Bay of Bengal; the west coast and desert zone of India; the Ganges River valley (for water-management studies); New Delhi and Agra. A total of 1,000 MKF-6M pictures and 200 KATE-140 photographs were obtained.[77]

### *Gyunesh and Black Sea Observation Programs*

Two international observation programs were performed during 1984 and continued in 1985.

*Gyunesh* was described as assisting in the preparation of long term forecasts for members of the Council for Mutual Economic Aid. The observations used sensors on the space station, aircraft, ships at sea, and the ground. Among the areas studied were the Greater Caucasus mountains, river valleys of Azerbaijan, and the Alazani valley. The Caucasus were chosen because of the many nature zones concentrated there. The "whole world is there in miniature" according to Cosmonaut Solovyev. In addition to perfecting methods of remote sensing, the data gained from the program were used to provide farmers with recommendations, maps and charts for management of agricultural lands, pastures and reservoirs. The countries that participated in the program were Bulgaria, Hungary, the German Democratic Republic, Cuba, Mongolia, Poland and Czechoslovakia.[78] Gyunesh reportedly was part of an international space project called "Study of Geosystem Dynamics by Remote Methods."[79]

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[75] Moscow World Service, 0800 GMT, February 29, 1984.

[76] Pravda, July 12, 1984.

[77] Sotsialisticheskaya Industriya, April 7, 1984; TASS, 1025 GMT, April 8, 1984; TASS, April 9, 1984; Moscow Television Service, 0655 GMT, April 23, 1984.

[78] Moscow Television Service, 1430 GMT, August 30, 1984; Bakinskiy Rabochiy, August 30, 1984.

[79] Vechernyaya Moskva, August 30, 1984; TASS, 1026 GMT, August 13, 1985.

The Soyuz T-13 crew in 1985 continued work under the same general program as Gyunesh, but called *Kursk-85*. Bulgaria, Hungary, Vietnam, East Germany, and Czechoslovakia participated in assessing crop conditions and developing forecasting methods for crop yields.[80]

The *Black Sea* was studied because it is a model for the ocean, with eddy currents, rising water columns, river outflows and shelf zones. Studies related to the Black Sea used sensors on the space station, the automated spacecraft Cosmos 1500 (with a side looking radar), airplanes, and the research ships "Mikhail Lomonosov" and "Professor Kolesnikov." Bulgaria, the German Democratic Republic, and Poland participated in the Black Sea studies.[81] In 1985, it was stated that the research was expected to yield information on the relationship between the air and the water basin "which in a number of cases determine the weather in a vast region," and that another reason for the interest in the Black Sea was that it was a major area of human activity and scientists want to understand how human activity affects the sea.[82]

### *Observations of Special Interest*

In 1985, the cosmonauts conducted a series of observations under the name *Cupola* to evaluate atmospheric pollution over industrial centers. In August 1985, the city of Zaporozhye was specifically named as an object of the studies.[83]

Also in August 1985, the Soviet media announced the Soyuz T-13 crew had spotted a range of ancient volcanoes in the Kyzylkum desert. The brief report noted that the space photographs showed ring structures dozens of kilometers in diameter encircling the crater of ancient volcanoes. Geologists were interested since these types of structures often indicate the presence of polymetallic ores.[84]

Another interesting observation by the Soyuz T-14 crew was a volcanic eruption in Colombia. Savinykh stated that they did not see the eruption, but they knew something was happening because "that night, suddenly, on the equator we saw silvery-colored clouds which shouldn't exist at all." He continued: "I was totally confused at first, racking my brains. What is this, silvery colored clouds at the equator?" On the next orbit, he did not see the clouds at all, but observed them on the next one. He described them as "so bright and white. A thinning white layer, this belt. . . . And in the morning we heard the report that in Colombia, precisely at the same spot, there had been a lot of material thrown up into the atmosphere. We observed it every day for 3 consecutive days."[85]

At the end of Soyuz T-14, *Pravda* noted that Savinykh was a graduate of the Moscow Institute of Engineers of Geodesy, Aerial Photography and Cartography and that the Institute's President, Vasiliy Bol'ahakov, had communicated with Savinykh while he was in space. Savinykh was asked to study the Aral Sea in particular, observations "which were begun as far back as Salyut 5." Bol'ahakov commented that comparisons of past and present data would allow important conclusions to be drawn about the future of the region, and that the Talas-Fergana fracture and the condition of Lake Issyk-Kul' were of special interest.[86]

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[80] Krasnaya Zvezda, June 25, 1986, p. 1

[81] Ibid.

[82] TASS, 1132 GMT, September 24, 1985.

[83] TASS, 1126 GMT, August 16, 1985.

[84] Moscow Domestic Service, 0720 GMT, September 5, 1985.

[85] Moscow Domestic Service, 1630 GMT, November 26, 1985.

## ASTRONOMY

A modest amount of astronomical observations were conducted during the 1984–1986 missions. Early in the Soyuz T–10/T–11 mission, the French Piramig instrument was used to study Crommelin's Comet as a rehearsal for studying Halley's Comet.[87] It was used again in July 1984 by the visiting Soyuz T–12 mission to study one of the Langrangian points to confirm whether or not there are concentrations of dust there.[88]

Progress 23 delivered two X-ray telescopes for conducting experiments under the name *Siren* (Lilac). One instrument, developed by the French, was a gas scintillation proportional spectrometer (GSPS), a successor to the French Piramig device, with a high resolving power. The other was the RS–17, built in Baku, that could detect hard X-ray radiation (2,000–800,000 electron volts).[89]

Both instruments were mounted in the adapter module so they could look in the same direction. Then they were connected to an electronic control panel in the command module and the adapter module was depressurized. A total of 46 observations were made, primarily of X-ray sources in the constellations Sagittarius and Cygnus (the latter was thought to be a possible location of a black hole) and the Crab Nebula, and of X-ray pulsars.

E. Yu. Salayev, president of the Azerbaijan Academy of Sciences, discussed the potential impact of these studies, saying that they would help in understanding the history of Earth's formation, but were also important:

> . . . for obtaining data on the state of plasma and thermonuclear reactions in objects that are observed. This is necessary so that information which is amassed can be utilized in the future in the development of highly effective thermonuclear units, while will be so essential for solving the acute problem of the energy crisis in our life on Earth.[90]

## ATMOSPHERIC STUDIES

Atmospheric studies also continued. As with remote sensing, these types of observations are so numerous that only major activities will be discussed. The Czechoslovakian *EFO–1* device was used for the "Ekstinktsiya" experiments to study the density of aerosol layers by measuring the change in the brightness of stars as they set behind the atmosphere.[91]

The *ASTRA–1* mass spectrometer was used throughout the 1984–1986 missions,[92] while mention was made of the *Yelena* gamma ray telescope only during 1984.[93] The *Mariya* device (described below) was stated to be a successor to Yelena, although the descriptions of their activities did not seem very similar and Mariya made observations in the X-ray, not gamma ray, wavelengths.

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[86] Pravda, November 22, 1985, p. 4.

[87] Pravda, February 27, 1984.

[88] Moscow Domestic Service, 0655 GMT, August 10, 1984.

[89] TASS, 1338 GMT, September 3, 1984; TASS, 0932 GMT, September 14, 1984; Pravda, September 21, 1984.

[90] Vyshka, October 6, 1984.

[91] Pravda, July 24, 1984; Pravda, August 3, 1984 .

[92] TASS, 1118 GMT, February 17, 1984; Izvestiya, July 3, 1985.

The Soyuz T-14 crew brought to Salyut 7 a spectrometer called *Skif* which was described as a "qualitatively new step in research" since it could photograph the atmosphere in the desired areas and requisite color range and immediately develop the film and analyze the picture.[94] At the end of the mission, Savinykh counted this as one of the most satisfying experiments that he conducted during the mission.[95] It was developed by the Byelorussian Academy of Sciences Institute of Physics. The instrument recorded spectral characteristics of objects and photographed them simultaneously with a motion picture camera. It had an internal computer that could check systems to ensure they were operating correctly, and display information to the operator on what was wrong. The computer would be programmed with instructions for conducting experiments.[96]

Cosmos 1686 brought the *Aerosol* experiment to study luminescent clouds, the gas composition of the atmosphere and its optical and spectral characteristics.[97]

In 1985, the Cosmos 1669 module brought the *Mariya* experiment for studying how high energy particles are generated in the Earth's radiation belt and low earth orbit. This was described as a successor to the Yelena instrument, although it studied X-rays rather than gamma rays, and the reports about its use implied that it was observing the internal atmosphere of the space station, not the Earth's atmosphere. Its measurements were available in a few minutes, rather than needing to wait until the flight was over to study the data. Mariya counted the number of electrons and positrons in the space station's environment; the particles are produced by the bombardment of the station's environment by cosmic rays.[98]

### MILITARY EXPERIMENTS

Speculation about military uses of Salyut continued in the West, but the Soviets (not surprisingly) made no mention of such activities. The U.S. magazine *Aviation Week and Space Technology* reported in January 1985 that Salyut cosmonauts "have conducted extensive manned military space operations in support of Soviet military ground, sea and air exercises." The magazine did not identify which Salyut crews were involved, but went on to enumerate some of the specific experiments. According to *Aviation Week* Salyut cosmonauts "participated in observation of Red Army exercises involving broad release of aerosols like those that could be smoke for concealment, gases or mists involved in fuel air explosive tests. The cosmonauts played at least a monitoring and assessment role in these tests and possibly a command and control role as well." Cosmonauts have "observed Soviet ABM test exercises," and

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[93] TASS, 1351 GMT, February 27, 1984.
[94] TASS, 1233 GMT, September 19, 1985.
[95] TASS, 1835 GMT, November 22, 1985.
[96] Sovetskaya Byelorussia, December 11, 1985, p. 2.
[97] TASS, 1337 GMT, October 22, 1985.
[98] Moscow Domestic Service, 1800 GMT, August 12, 1985.

"cosmonaut observations have been an integral part of some Soviet naval exercises, with some surface ship activities specifically coordinated with overflight of the space station. The Soviet cosmonauts performed at least an intelligence role and possibly a command and control role as well." Cosmonauts and sensors "used in military-oriented laser tests, where ground-based lasers have been used to illuminate the station." Cosmonauts have "used hardware delivered to the station to demonstrate space-based laser target acquisition and laser target tracking."[99] There is no information in the unclassified literature to confirm or deny these comments.

## 1984 ACTIVITIES

During 1984, Salyut 7 was occupied by one long duration crew that set a new endurance record of 237 days. The main crew was visited by two others, one of which included the first Indian cosmonaut, and the other involved the first spacewalk by a woman. Five resupply missions were flown by Progress spacecraft during the year. The Soyuz T-10/T-11 crew was notable not only for the length of time they stayed in orbit—a new endurance record—but for the major repair work they performed on the space station itself.

### SOYUZ T-10/T-11: 237 DAY MISSION

Soyuz T-10 was launched at 15:07 Moscow Time[100] on February 8, 1984. The crew, using the call sign Mayak (Beacon) consisted of Col. Leonid Denisovich Kizim, pilot, on his second flight; Vladimir Alekseyevich Solovyev, flight engineer; and Oleg Yur'yevich Atkov (a physician), cosmonaut researcher. This was only the second time the Soviets sent a physician into space.

The crew docked with Salyut 7 at 17:43 Moscow Time (MT) on February 9, 1984 to begin a record breaking mission of 237 days, landing on October 2, 1984. During the flight, they performed a record number of EVAs to repair a fuel leak and install additional solar panels. There were only a few days that either a Progress or a visiting Soyuz was not part of the space complex. At the end of the record-breaking mission, TASS commented that the 237 day flight "is precisely the time which an outer space craft needs to reach Mars with the modern level of technology."[101]

#### *Docking and Initial Operations*

An account of the docking reported in *Pravda*[102] emphasized that although routine, dockings can still be challenging. According to the transcript of communications between other cosmonauts at the Flight Control Center and the crew, Kizim reported that he could not see the cross on the space station with which to align his craft. Cosmonaut Vladimir Lyakhov at Flight Control reported that it was because of the sun and warned Kizim "You must be very careful and don't hurry . . . Lenya, more gently." Cosmonaut Valeriy Ryumin interjected "More carefully, watch what you're doing," after which Kizim responded that "We have gotten very close" and he was going to back away. Kizim then said he had a good view of the station's lights and shortly thereafter reported that docking had been achieved.

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[99] Salyut Cosmonauts Support Military Exercises. Aviation Week and Space Technology, January 28, 1985, p. 22

[100] Since the information on the Soviet missions is given in Moscow Time (MT) by the Soviets, MT is used in this report as well. To convert to Greenwich Mean Time subtract three hours from Moscow Standard Time or four hours from Moscow Summer Time. They go onto Moscow Summer Time the last weekend in March and resume Moscow Standard Time the last weekend of September.

[101] TASS, 1441 GMT, October 18, 1984.

[102] Pravda, February 11, 1984.

At the beginning of the mission, deputy flight director Blagov noted that the crew's daily work schedule had been changed, based on experience with the Soyuz T–9 crew.[103] The crew's working day was lengthened to 8.5 hours, and in general a day included a half-hour for preparing instruments and equipment, six hours for conducting experiments and observations, an hour for looking over plans for the following day's work, nine hours for sleep, two for physical conditioning exercises and the rest for meals, conversations with the Flight Control Center, leisure and non-duty communications with the ground. The Soviets also decided to schedule work so that similar experiments (geophysical observations, materials processing, etc) are done sequentially to conserve time, especially that needed to reorient the space station. The schedule obviously could not always be strictly observed. It was noted that the crew had spent 40 minutes looking for a cable that was not in its designated spot, causing difficulties in maintaining their schedule for that day. It was also noted that Kizim was inflexible in responding to these delays. "He allows no one to rest, either his comrades or the Mission Control Center until the day's program is completely carried out. . . . Certain instruments they must look for not for 5 minutes as the instructions state, but longer. Seemingly this might justify various delays. But Kizim was inflexible."[104] The crew worked five days a week, eight hours a day, with two days off.

The crew's first task was reactivating the space station. By February 18, press reports stated that the water regeneration system was back in operation, the crew had replaced a number of fans, inspected windows, and checked orientation systems.[105]

Less then two weeks after the crew boarded Salyut 7, a resupply mission was launched. Progress 19 was sent up at 09:46 MT on February 21 and docked at 11:21 MT on February 23. It carried 2,094 kilograms (kg) of cargo, including 800 kg of fuel, oxidizer, oxygen and water. The remainder of the cargo included more than 300 kg of food, a portable cardiograph to add to the echocardiograph already there, plus many Indian experiments for the joint mission with Soyuz T–11. Newspapers, letters and parcels from relatives and friends were also carried. With this mission, procedures were changed regarding unloading of cargo craft. Formerly, three days were set aside specifically for unloading. Beginning with this crew, they took what they wanted as they needed it.[106] Progress 19 undocked on March 31 and reentered on April 2.

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[103] Izvestiya, February 17, 1984.
[104] Pravda, February 19, 1984.
[105] Izvestiya, February 18, 1984.
[106] Izvestiya, February 25, 1984.

Next came the launch of Soyuz T-11 carrying a three man crew including an Indian (see next section). They arrived on April 4 and left on April 11, returning to Earth in the Soyuz T-10 spacecraft. On April 13, the main crew moved the Soyuz T-11 spacecraft to the forward port, freeing the aft port for another Progress mission. Progress 20 was launched at 12:13 MT on April 15 and docked with the space complex on April 17 at 13:22 MT. It undocked on May 6 at 21:46 MT and was deorbited on May 7.

While Progress 20 was docked with the space station, the crew performed four of their six EVAs. In fact, a special extension was affixed to Progress 20 that Kizim used during his work on the engine unit. Details of the EVAs are given below. The day after Progress 20 reentered, Progress 21 was launched at 02:27 MT. It docked with the complex on May 10 at 04:10 MT. Another EVA, to install additional solar panels, was conducted after it docked. Progress 21 undocked at 13:41 MT on May 26 and was deorbited. Progress 22 was launched two days later at 18:13 MT and docked at 19:47 MT on May 30. On June 3, Pravda quoted Blagov as explaining that one reason the Progress flights were occurring more frequently was that there were three people on board instead of two, and the air supply had been depleted by all the EVAs.[107] At 17:36 on July 15, Progress 22 undocked and deorbited.

Another visiting mission, Soyuz T-12 was the next mission to Salyut 7. The Soyuz T-12 crew docked on July 18 and left on July 29, a somewhat longer visiting mission than usual. On August 8, the main crew performed the sixth and last EVA using equipment brought by the T-12 crew and based on training provided by Dzhanibekov. Unlike the previous EVAs, no Progress was docked with the space station this time, although it was only six days later that another resupply mission was launched. Progress 23, launched on August 14 at 10:28 MT, docked with the complex on August 16 at 12:11 MT. It undocked just 10 days later at 20:13 MT and was deorbited on August 28 at 05:28 MT.

### *Details of the Six EVAs*

On all six EVAs, Kizim and Solovyev operated outside the space station, while Atkov remained inside monitoring systems and assisting where possible. Kizim and Solovyev each spent a total of 22 hours 50 minutes on EVA. By comparison, the most time accumulated by a U.S. astronaut crew was 22 hours 21 minutes on Skylab. In summary, the EVAs were as follows: (1) April 23, 4 hours 15 minutes; (2) April 26, 5 hours; (3) April 29, 2 hours 45 minutes; (4) May 4, 2 hours 45 minutes; (5) May 18, 3 hours 5 minutes; and (6) August 8, 5 hours. Considering that it had been only in 1983 that a crew had performed two EVAs on one mission, this was a considerable expansion of Soviet EVA activity.

#### *Repairing the Fuel Leak*

Five of the six EVAs were needed to repair a fuel leak in one of the oxidizer lines that occurred in September 1983. Ground control determined that there was no danger to the Soyuz T-9 crew that was aboard the space station at the time and their mission continued until November 1983. In 1984, however, they decided that the problem should be repaired not only because it troubled specialists on the ground, but because the Soviets wanted to gain experience in conducting repair operations.[108] Prior to the mission, the cosmonauts performed specific operations in an IL-76 aircraft, in addition to the typical tests of procedures in their water tank.[109]

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[107] Pravda, June 3, 1984, p. 3.

*EVA 1.* It took four EVAs for the crew to establish their base of operations outside the space station, set up two cross-pieces to bypass the failed fuel line, and precisely locate the depressurization. These spacewalks took place over the relatively short time period between April 23 and May 4.[110]

EVA 1 took place on April 23. The exit hatch opened at 08:31 MT and the crew remained outside for 4 hours and 15 minutes. During this time, the crew essentially prepared for the work to follow. By driving special anchor pins into the exterior of the space station, they installed a special ladder. They then fastened containers with tools and materials next to it. The kit developed for the repairs included 25 specially made tools weighing 40 kg.

*EVA 2 and 3.* EVA 2 occurred on April 26; the hatch was opened at 06:40 MT. During the five hour EVA, the crew opened the protective cover on the engine compartment and installed a valve. The conduit was blown and its airtightness checked. They cut a window in the plastic exterior of the station to gain access to a control filler on an oxidizer line. The filler had a plug fastened with a nut which was covered with an epoxy putty. Removal of the nut was very difficult and required two hours and a special wrench that imparted increased torque on the nut.

With the filler open, they replaced a valve in the line. Then on Atkov's command, the line was pressurized with nitrogen from Progress 20. Kizim and Solovyev reported that they were not tired and asked for more time. The EVA was originally scheduled for 4 hours 5 minutes, but lasted 5 hours instead.[111]

The work took place during the early morning hours in Moscow so the crew's activities could be monitored during daylight flyovers. This scheduling, combined with tracking ships in the Atlantic and Pacific, extended the period of radio visibility from 20 to 50 minutes. The cosmonauts had to move along the entire length of the complex using a handrail. The work was directed by cosmonaut Valeriy Ryumin at the Flight Control Center. Kizim anchored himself on a special extension that had been built for this purpose into Progress 20, docked at the aft end near the engine compartment.[112]

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[108] Ovchinnikov, V.S. Experience of the Salyut-7 Propulsion System (PS) Repair Operations. Paper presented to the 38th Congress of the International Astronautical Federation, Brighton, England, October 10-17, 1987. IAF-87-87. p. 2.

[109] Both the United States and the Soviet Union use water tanks for crews to test out EVA procedures. They are sometimes called "neutral buoyancy simulators" and approximate the conditions of weightlessness. The Soviets have a full scale mock-up of their space station in a water tank at Star City where the cosmonauts live and train.

[110] Details of the EVAs were provided in a paper by Solovyev at the 1987 International Astronautical Federation conference in Brighton, England ("Man in Space," IAF-97-77).

[111] Komsomolskaya Pravda, April 27, 1984.

[112] Gudok, April 27, 1984.

After a three day rest, another EVA was completed. EVA 3 started at 05:35 MT on April 29 and lasted 2 hours and 45 minutes. The crew connected both filler tubes with a metal bypass line which was then checked with nitrogen from Progress 20. The station's thermal protective coating was restored to ensure the stability of thermal conditions on the orbital station.

*EVA 4.* The fourth EVA, on May 4, lasted 2 hours and 45 minutes. The crew opened the hatch at 03:15 MT. They removed the thermal protective coating that had been installed on EVA 3, assembled a second conduit, checked it for air tightness, reinstalled heat resistant coating, put tools into their container and returned to the station. It was only on this EVA that they finally located the point of depressurization precisely.[113] It became clear they would need special tools to repair the leak, so the effort was temporarily suspended until the Soyuz T-12 crew could visit and bring the proper tools and training. Thus, the next EVA conducted by the main crew was for installing solar panels (see below), and the fifth EVA for repairing the fuel line was actually the sixth that the crew performed.

*EVA-6.* This last EVA occurred on August 8. The hatch was opened at 12:46 MT and the crew remained outside for five hours. After again removing the thermal protective cover, the crew used a special tool to permanently seal the leaking fuel line. The fuel line was made of stainless steel and had to be sealed in one operation, so a pneumatic press was developed for the work that could exert a force of 5 tons. The press was delivered by the Soyuz T-12 crew and Dzhanibekov had been trained on its operation. In an August 10 press conference, deputy flight director Blagov stated that Dzhanibekov had in fact been trained to perform the repair in orbit, but Kizim and Solovyev "requested and were granted permission to complete the job." (Dzhanibekov did perform an EVA, however, as discussed under the Soyuz T-12 heading.) Dzhanibekov brought with him part of an engine which the crew assembled and fastened to a wall of Salyut 7 so he could demonstrate how to complete the task. Videotape, photographs, methodological directions and other aids were also provided.[114]

In addition to fixing the fuel line, the crew cut out a piece of a solar panel for return to Earth so the processes of aging could be analyzed. "There are many factors which we cannot reproduce on Earth for various reasons. Therefore, we want to obtain a 'live' piece of solar battery so that a qualitative analysis can be carried out in terrestrial conditions."[115] A special cutting tool was developed for this task so the crew could cut the panel without touching it with their hands.[116]

After the crew was home, Prof. Konstantin Feoktistov commented that they had known the work would require several EVAs, but "the most unlikely variant appeared to be one which would require six walks by the cosmonauts. I'll be honest and admit that I thought we could do it with fewer. But it turned out that it was precisely this variant that was necessary." He complimented Kizim and Solovyev for performing "brilliantly. Their experience undoubtedly has enriched manned space flight."[117] Solovyev recounted his experiences in 1987 and commented that at first it was difficult just to move from one end of the station to the other. "We had to stop very often and sometimes return to free the catched tether or to take the tools or TV camera out of [an] undesirable position. The experience was gained after the second and third EVA's and later we . . . got the hang of doing it and passed our route 'almost running'."[118]

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[113] Aerospace Daily, August 16, 1984, p. 259

[114] Moscow TV Service, 1700 GMT, August 8, 1984; Pravda, August 8, 1984; Trud, August 9, 1984; Aerospace Daily, August 16, 1984, p. 259

[115] Moscow TV Service, 1700 GMT, August 8, 1984.

[116] Pravda, August 8, 1984.

### *EVA 5: Installing Gallium Arsenide Solar Panels*

On the fifth of the six EVAs, on May 18, the crew installed two additions on either side of one of the main Salyut solar arrays. The hatch was opened at 21:52 MT and the EVA lasted 3 hours and 5 minutes. Kizim and Solovyev attached a new small solar panel on one side of the array, after which Atkov, inside the station, rotated the solar panel 180 degrees to ease installation of the second panel. The most important feature of the new additions was that they were made of gallium arsenide rather than silicon. According to the Soviets, each gallium arsenide panel provided a maximum charge current of 20 amps, 6 amps more than that of a silicon battery. The extra panels increased the area of the station's solar arrays by more than 9 square meters and increased electrical power by 1.2 kilowatts. Solovyev reported that a handle on the winch used to extend the panels accordion-style broke, and that they disposed of the panel's containers by throwing them into space (taking care to put them into a different orbit so the station would not "encounter" them in the future).[119]

### *End of Mission and Return to Earth*

On September 5, the three-man crew equalled the 211 day record set in 1982. Physicians on the ground commented that they were "completely happy" with the crew's health, saying that the body mass of one had risen, one stayed the same and the third had fallen, but all within norms. The volume of tibia had decreased by an average of 15 percent. They noted the two problems of greatest concern: preventing muscle volume decrease and maintaining the psychological climate on board. "For example, the cosmonauts asked [the] Flight Control Center not to assign tasks to specific crew members. They asked that the distribution of duties be left to them. Ground control acceded to their request. Throughout the flight, television meetings with their families have been arranged for the cosmonauts. This has helped them. Incidentally, it was during such a session that Leonid Kizim learned that a daughter had been born in his family."[120] Another comment was that the cosmonauts had taken all their vitamins, but had not touched their supply of medicines. "None of the crew has suffered from influenza, acute respiratory illnesses or angina."[121]

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[117] Pravda, October 3, 1984.

[118] Solovyev, op. cit.

[119] Trud, May 20, 1984 .

[120] TASS, 1445 GMT, September 6, 1984. Kizim's daughter was born in May (Pravda, October 3, 1984).

On September 24, Moscow television brought the news that the cosmonauts "proudly report" that they managed to save 350 kg of fuel through optimum procedures of correction and orientation of the station.[122] Two days later, *Izvestiya* announced that the crew was preparing for return to Earth.

October 1 brought a report that the crew was checking out Soyuz T-11, and there was a televised report from the crew that revealed their feelings about returning to Earth. Kizim commented that they had covered a distance greater than that from the Earth to the Sun, and all the seasons had passed on Earth. ". . . [T]he crew gains experience with time. We now remember the first weeks on the station with a smile, and sometimes with the slight feeling of awkwardness." Atkov added: "We have met our friends gladly, twice, and seen them off with sadness. Those were exciting, memorable days of our joint work." Solovyev concluded that five Progress craft brought not just fuel and oxygen "but also the smells of native earth, letters from our close ones and acquaintances, and sometimes from people who are strangers, but very kind. We were sent fresh bilberries [sic] and strawberries. Throughout the flight, we have constantly felt the reliable support of the Flight Control Center and of all the measurement complexes on land and on ships. This was like the shoulder of a friend, and we are very grateful to all. . . . [The] psychological support group organized . . . interesting encounters. People made us presents of their poetry, songs, and stories, and gave us a lot of support through this. Now, of course, we are a little sad. The minute of leaving the station is arriving and the station has become a second home for us. But we are not saying farewell to space, we are saying au revoir."[123]

The crew, which had been launched on Soyuz T-10, landed at 13:57 Moscow Time on October 2, 1984 in Soyuz T-11, 160 km east of Dzhezkazgan. The crew had been in space for 236 days 22 hours and 50 minutes. Kizim reportedly said upon landing that he was feeling "not very well yet, but that's only to be expected now that we're back in the Earth's embrace. But generally I feel normal," while Solovyev commented that he felt "strange."[124]

The next day, General Vladimir Shatalov,[125] head of cosmonaut training, discussed the psychological condition of the crew. "The fact that the crew was surprisingly harmonious, was always in good form, and in a good mood, is a credit to the psychological support group, which joined in communications 150 times. But it is probably not just to their credit." Everyone was concerned about how the crew would get along for such a long time, including the other cosmonauts, "knowing that over a period of 2-3 months it is not always easy to maintain mutual sympathy and to be able to work without arguing in such a way that the work is affected. . . . This is greatly to the credit of all who took part in the selection of the cosmonauts . . . " and "first and foremost" to the cosmonauts themselves who managed "to foster these qualities in themselves: the ability not to notice their comrades' shortcomings, or to react to them correctly, and being able to find the correct solution to any situation in order to make it possible to continue working together successfully on board the station."[126]

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[121] Sovetskaya Rossiya, September 7, 1984.

[122] Moscow Television Service, 1430 GMT, September 24, 1984.

[123] Moscow Television Service, 1530 GMT, October 1, 1984.

[124] Quoted in Defense Daily, October 4, 1984, p. 174.

[125] General Shatalov, a cosmonaut who flew on three space missions, is often referred to in the Soviet press as the head of the Gagarin Cosmonaut Training Center. General Beregovoy, another cosmonaut, is also referred to with the same title. They apparently are co-directors of the center, with Beregovoy in charge of management and Shatalov in charge of training.

A week after landing, Moscow television reported that Atkov was 5-6 cm taller than when he left, and Solovyev and Kizim had noticed that their Earth clothing has become a bit small. Calcium, magnesium and phosphorous levels were said to be returning to normal and "Readaptation . . . is proceeding ahead of schedule." Atkov was asked whether the good psychological environment among the crew may have helped them remain healthy and he replied: "Yes, of course, because to a certain degree we were mounting an experiment in the interests of pure psychology. . . . [T]his crew—our crew—if we were to gather again for any kind of work, it would work for sure, since we have found out that we can do anything. That is, I think that a man is sufficiently profound, unlimited, and that human qualities can be opened up virtually limitless through a whole life."[127]

By October 17, the comment was made that Solovyev, "a tall man, is more prone to orthostatic changes than his crewmates. This is taken into consideration during the readaptation," and the crew members "swim with pleasure in a swimming pool and, under physicians' control increase the length of their strolls in the open air."[128]

### SOYUZ T-11/T-10: FIRST INDIAN COSMONAUT

Soyuz T-11 was launched at 17:09 MT[129] on April 3, 1984. The mission included an Indian cosmonaut and the launch was shown live on Soviet television. The mission followed a typical profile for a visiting crew, landing eight days later, on April 11, in the Soyuz T-10 spacecraft.

The crew, call sign Jupiter, included Col. Yuriy Vasilyevich Malyshev, commander; Gennadiy Mikhaylovich Strekalov,[130] flight engineer; and Maj. Rakesh Sharma of the Indian Air Force, cosmonaut researcher. The three men docked with Salyut 7 and the Soyuz T-10 crew on April 4 at 18:31 MT. Sharma brought with him an Indian national flag and soil from India.

The announcement of the launch date and time was made a week in advance, and it was noted in the Soviet press that a Salyut 7 orbital correction on March 30 was in preparation for the Soviet/Indian flight. That day the Soviet press also announced the docking time, landing date and place. In addition, it was stated that a "telebridge" would be established with Delhi on April 5. This was accomplished using Intelsat and Soviet communication satellite links and Indian Prime Minister Indira Gandhi spoke with the crew. Experiments that would be conducted by the crew were also described.[131]

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[126] Moscow Domestic Service, 0900 GMT, October 3,1984.

[127] Moscow Television Service, 1530 GMT, October 9, 1984.

[128] TASS, 1006 GMT, October 17, 1984.

[129] Soviet press reports conflicted in their announcement of the launch time, with some reporting 17:08 Moscow Time and others 17:09 MT. This report uses the 17:09 MT launch, based on information from the Kettering Group.

[130] Strekalov replaced Nikolay Rukavishnikov in February because of illness (TASS, 1700 GMT, February 27, 1984).

The experiments were in three main areas (medical, materials processing, and remote sensing) and are discussed in the section on experiments. In summary, the crew participated in several medical experiments related to space motion sickness, including the Indian Yoga exercises conducted by Sharma. The materials processing studies were of silver-germanium samples and the remote sensing studies were under the "Terra" designation. As was customary, Sharma brought some native foods with him (pineapple and mango juice, "crisp" bananas, and mango fruit bars) and Indian music.

Cosmonauts spoke with family and friends at the end of the second day on the space station. The rest of the week was spent conducting the various experiments.

The crew returned in Soyuz T-10, which undocked on April 11 and landed at 14:50 MT, 46 km east of Arkalyk. The crew had spent 7 days 21 hours and 41 minutes in space. The Soyuz T-10 descent module was presented to the Indian government on January 31, 1985 and placed on display in New Delhi's Jawahar Lal Nehru Planetarium.

## SOYUZ T-12: THE FIRST EVA BY A WOMAN

Soyuz T-12 was launched on July 17, 1984 at 21:41 MT and remained in space for 12 days, landing on July 29 at 16:55 MT, 140 km southeast of Dzhezkagan. The crew, call sign Pamir, was comprised of three Soviet cosmonauts: Col. Vladimir Aleksandrovich Dzhanibekov, commander, on his fourth spaceflight; Svetlana Yevgeniyevna Savitskaya, flight engineer, on her second flight; and Igor Petrovich Volk, cosmonaut-researcher, on his first mission. On this flight, Savitskaya became the first woman to make an EVA and the first woman to make a second spaceflight.[132]

The Salyut 7 space station and the Soyuz T-10/T-11 crew were in a relatively high orbit at the time of the Soyuz T-12 launch. Western observers previously had speculated that a Soyuz carrying three crew members could not be launched to such a high orbit (approximately 350 by 330 kilometers), but this launch negated those speculations.[133]

The Soyuz T-12 crew docked with Salyut 7 at 23:17 MT on July 18 for 11 days of joint operations with the main Soyuz T-10/T-11 crew, a mission four days longer than typical visiting missions to space stations. *Pravda* reported that with the Soyuz T-12 docking, for the first time data from the arriving spacecraft's video display was transmitted not only to the Flight Control Center on the ground, but to the space station as well.[134]

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[131] Moscow Television Service, 1800 GMT, March 28, 1984; Leningradskaya Pravda, March 31, 1984; TASS, 1552 GMT, March 30, 1984; TASS, 1909 GMT, March 30, 1984; Delhi Domestic Service, 1530 GMT, April 5, 1984.

[132] The Western press noted that by flying Savitskaya on this mission, the Soviets had "upstaged" the United States which was planning a flight for the fall of 1984 (STS 41-G) in which Kathryn Sullivan would make an EVA and Sally Ride would made her second spaceflight (Russian Astronaut Becomes First Woman to Walk in Space, New York Times, July 26, 1984, p. A 24.) Whether this actually was a factor in the Soviet planning is conjectural.

[133] Soyuz T-12 Docks with Salyut, Aerospace Daily, July 20, 1984, p. 106.

### *Major Tasks*

The two major tasks were instructing the main crew how to complete repairs to the Salyut 7 fuel line, and performing a spacewalk to demonstrate the use of a new tool for cutting, welding, soldering and spraying coatings. The tutoring provided to the main crew by Dzhanibekov is discussed under Soyuz T-10/T-11, while the major activities and results of Dzhanibekov's and Savitskaya's EVA are included under the "Experiments" section. The T-12 crew also performed a number of experiments with the Tavria unit, visual photography, microbiological experiments related to the permeability of cell membranes, a resonance experiment to study the dynamic characteristics of the space complex, an evaluation of the effectiveness of various materials used in filters for air purification on the space station, medical studies (especially cardiography and space motion sickness), study of the interplanetary medium, and production of hermetic sealing mixtures. The number of experiments required the crew to work especially long hours, and on July 24, the day before the Dzhanibekov/Savitskaya EVA, it was reported that the working day started at 9:00 am and lasted until midnight.[135] The experiments conducted by the T-12 crew are described in the "Experiments" section under each appropriate heading.

### *Savitskaya's EVA*

On July 25, Dzhanibekov and Savitskaya performed a 3 hour 35 minute EVA to demonstrate the use of a new tool, called the URI, opening the hatch at 18:55 Moscow Time. The experiments are described in the "Experiments" section, but essentially involved use of the URI electron beam gun for (1) cutting, soldering and welding; and (2) spraying coatings on surfaces. The two crew members also retrieved containers holding a variety of materials from the outside of Salyut for testing their durability under spaceflight conditions and replaced them with new ones. It was reported that they had placed an experiment called "Meduza" on the outside of the station for the "abiogenic synthesis of components of nucleic acids," but no further details were given.[136]

Savitskaya recounted her EVA experience at a press conference following the flight. She said that after exiting the hatch, Dzhanibekov had set up a lamp, removed one of the samples to be taken inside, and then transferred to the working platform. He attached the URI to a handrail, then she transferred to the work platform, attaching herself using a special anchor. Using the URI, she cut a titanium sample that was 0.5 millimeters (mm) thick. She then welded on samples 1 mm thick, soldered, and finally sprayed a thin layer of silver on anodized aluminum plate. Some of the experiments were done with titanium and others with stainless steel. The thickness of the samples also varied.

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[134] Pravda, August 17, 1984, p. 3.
[135] Pravda, July 24, 1984.
[136] Krasnaya Zvezda, August 1, 1984, p. 1.

As she completed these tasks, the space complex passed into the Earth's shadow, so both cosmonauts rested and enjoyed the view. When they reentered sunlight, the two changed places and Dzhanibekov carried out the remainder of the work. Six welding experiments were done, two with titanium and four with stainless steel. Six cutting experiments, three of titanium and three with stainless steel. Six soldering experiments with tin and lead solder. Two experiments in applying a silver coating to the anodized aluminum. All were returned to Earth for study. The hatch was closed at 21:30. Both cosmonauts commented that the tool they tested for soldering, welding and cutting, and spraying coatings on materials, would be very useful in the future for assembling and erecting space stations. The tasks performed by the cosmonauts was described as "intensive" and it was noted that the electron gun they used got hot and special safety precautions had to be taken.[137]

### *Post-Flight Press Conference*

A week after their July 29 landing (for a mission duration of 11 days 19 hours and 14 minutes), the cosmonauts gave an extensive post-flight press conference on August 10, 1984. After recounting her experience as detailed above, Savitskaya commented that it had shown the "simplicity and safety of the operations with the URI and confirmed its reliability and efficiency." She added: "Having done this work, I can say that women are quite capable of doing it."[138]

Dzhanibekov expressed regret that he had not taken part in a lengthy program and expressed readiness to take part in such a program (his chance came in 1985 as discussed below). He complimented the main crew, saying that "Their sense of tact is amazing. It parallels their mutual supervision and help and their mutual support, which may not be very explicit but which can be seen very well all the same." He added that "If it had not been for this attitude, it might have been harder in some respects for us to work with Svetlana." He later commented that Savitskaya, had "demonstrated the stamina and strength comparable to those of a man" during the EVA.[139]

### *Future of Women on Soviet Space Crews*

General Shatalov, head of cosmonaut training, noted that Savitskaya's two flights had shown that women could work effectively in space, and that mixed crews would work on board third-generation space stations. "Of course, there will always be a certain division of labor, in my opinion. Thus, it is still best for the installation of bulky structures and the unloading of Progress spacecraft to be done by men. On the other hand, onboard medical personnel and meteorologists can be women. I also don't rule out the possibility of flights on stations by crews consisting entirely of women. The scientific program is becoming progressively more complex, and it is becoming necessary to send into orbit persons who are more and more 'narrowly' specialized. Among them are a considerable number of women. We are now convinced that they can work in orbit just as successfully as men."[140]

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[137] Moscow Television Service, 2105 GMT, July 25, 1984.
[138] Moscow Domestic Service, 0655 GMT, August 10, 1984.
[139] TASS, 0908 GMT, August 10, 1984.

## 1985 ACTIVITIES

### SOYUZ T-13 AND T-14: RESURRECTING SALYUT 7; FIRST CREW ROTATION

In 1985, the Soviets finally accomplished what many Western analysts had expected for years: the transfer of operations from one crew to another. The two-man Soyuz T-13 crew first occupied Salyut 7 and later was joined by the three-man Soyuz T-14 crew for a week of joint operations. Then one member of the T-13 crew returned to Earth with one of the T-14 crew members, while the other T-13 individual remained on board the space station with the other two members of the T-14 crew. This was not exactly what Western observers had anticipated—the replacement of one entire crew with another with no break in operations—but it accomplished the same purpose. The new crew's mission was terminated early because one of them became ill, but the procedures for transferring crew operations without interruption had already been demonstrated. Two resupply missions were flown (one of which was given a Cosmos rather than Progress designation for unknown reasons), and one large module docked with the station.

#### *Soyuz T-13*

Launched on June 6, 1985 at 10:40 Moscow Time, Soyuz T-13 carried two cosmonauts using the call sign "Pamir": Col. Vladimir Dzhanibekov, the most experienced cosmonaut making his fifth spaceflight; and Viktor Savinykh, making his second. This mission already assured itself a place in the history books even before the crew transfer, since the two-man crew literally resurrected the space station.

Everything appeared normal with Salyut 7 at the end of 1984. A December 20th report in *Izvestiya* gave its orbital parameters as 387 x 386 kilometers and it had made 15,407 revolutions of the Earth during its 32 months in orbit. The report concluded "The station's onboard systems are functioning normally."[141] All that changed by March, 1985, however. In a surprise announcement on March 1, TASS concluded a summary of the activities that had been conducted on the space station since 1982 with the statement: "As the planned program of work aboard the Salyut-7 orbital station has been fulfilled, the station was mothballed and continues its flight in an automatic regime."[142] The phrase that the work of a mission "has been fulfilled" had always signaled termination of operations in the past. It appeared that Salyut 7 was finished. Western experts speculated that the fuel line repair work by Kizim and Solovyev had not been successful, or that a new space station was being readied for launch.[143] Two months later, reports in the Western trade press stated that an electrical problem had disabled the space station and it would not respond to commands from the ground, but that visual observations indicated that it was "stable and not tumbling."[144]

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[140] Trud, July 31, 1984, p. 3.

[141] Izvestiya, December 20, 1984, p. 1.

[142] TASS, 1208 GMT, March 1, 1985.

[143] Salyut 7 Work "Fulfilled," TASS Says; Salyut 8 Seen Being Readied. Aerospace Daily, March 4, 1985, p. 12.

### *Reviving Salyut 7*

Thus it was quite a surprise in the West when Soyuz T-13 was launched in June to dock with the station. Not only was it thought that Salyut 7 would not be occupied again, but according to the Kettering Group, the launch took place outside the normal launch window parameters used on Soviet missions.[145] While the T-13 crew was effecting repairs, Soviet press reports provided few indications of the Salyut troubles, but Dzhanibekov detailed them after he returned to Earth. A personal account was written for the July 27, 1986 issue of the U.S. Sunday newspaper supplement *Parade.*

The Soviets knew that there were problems aboard the station because they had lost communication with it and the station had gone out of control,[146] but they did not know the extent of the difficulties and the decision to mount a repair mission was made even though they did not fully understand what had happened.

The first indication of how bad things really were was when the crew approached the space station and found that the solar panels were not parallel as they should have been, but were turned at a 70-90 degree angle.[147] This meant either that the panels' orientation system was not working or the electrical supply had ceased, causing the panels to stop in that position. In any case, the station was without electrical power. They also noticed that the exterior of the station was no longer green, but gray tinged with rust, "the thermostating soft envelope had burned out."

The first problem was docking, no small feat since the radar on Salyut that would normally help guide them into the port was not functioning. It became clear why these two particular cosmonauts had been chosen for the mission. Dzhanibekov had docked with space stations several times previously, manually as well as automatically, including one difficult docking with Soyuz T-6.[148] Savinykh had helped design the station, and was already in training to be part of what would have been the next crew to Salyut 7.[149] Dzhanibekov and Savinykh began training in March 1985 for the rescue mission.[150]

To slow their closing speed, the crew took two days to rendezvous with the station instead of one. A special set of instruments had been developed for the docking which included an optical guidance instrument, a laser range finder, and a night vision device. Dzhanibekov later recounted that he had assumed manual control at a distance of 3 km from the station, and began watching the station from a side window to which designers had moved the controls of the spaceships especially for this mission. At a distance of 200 meters, he reduced his relative speed to zero so that he could move to the side and fly around the station. At that point Dzhanibekov moved to his regular seat and, looking through the sight, flew around the station and approached the docking mechanisms.[151] Cosmonaut Feoktistov lauded the new docking procedure, saying that it might enable maintenance work on satellites and the rescue of stranded space crews.[152] The manual docking was achieved at 12:50 MT on June 8.

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[144] Electrical Problem Seen Disabling Salyut 7. Aerospace Daily, April 30, 1985, pp. 338-339.

[145] Soviets Launch Two Cosmonauts in Soyuz T-13. Aerospace Daily, June 7, 1985, p. 210.

[146] Unless otherwise noted, all the information for this section is from Dzhanibekov's article "Rescue in Outer Space," Parade, July 27, 1986, pp. 12-14.

[147] Krasnaya Zvezda, September 29, 1985, p. 4.

[148] After the mission, a Pravda article noted that on Soyuz T-6 (with French cosmonaut Chretien aboard), Dzhanibekov had made "a quick decision to assume manual control about 1,000 meters from the station" which nobody had done before, and this could be why he was chosen for this mission. Dzhanibekov cited others who could have performed the mission, including Popov, Malyshev and Romanenko. (Pravda, October 8, 1985, p. 3.)

[149] Pravda, October 8, 1985, p. 8.

[150] Krasnaya Zvezda, September 28, 1985, p. 4.

The crew could not get an internal pressure reading because of the electrical failure, so opened a valve to equalize the pressure between the Soyuz and Salyut.[153] The crew donned gas masks (in case there had been a fire caused by a short-circuit which could have left toxic substances in the air)[154] and moved into the station. Upon entering, they did not initially notice anything awry, and removed their gas masks. When they attempted to turn on the lights, however, nothing happened. The fans were quiet and the voltage indicators on the storage batteries read zero. They noticed that it wasn't simply cool in the station, "it was cold, freezing," and there was frost on the windows and equipment. This caused them great concern since the station's instruments were not designed to function at such temperatures. Due to the cold, the pressure had fallen to 714 mm Hg from its normal level of 780–800 mm Hg.[155]

Using the Soyuz to communicate with ground control (in which they also slept until the station was repaired), they received instructions about reactivating the station. Fortunately, six of the eight batteries were still usable, and the crew discarded the other two.[156] Their first task was to connect the solar panels directly to the storage batteries to recharge them, working during the sunlit part of the orbit not only because that was when the solar arrays collected sunlight, but because it was too cold to work. " . . . we would have to 'run' into the transport ship to warm up. We would work about 40 minutes, and then we would go warm up."[157] Prepared for the worst, they had brought special fur suits complete with gloves, but to work on the equipment they had to make long slits in the gloves, and their feet were especially cold. Recharging began on June 10.[158] "Finally, after a whole day of arduous work, we had the thrill of seeing the voltage needle tremble, move slowly off zero and begin to climb. You can imagine our joy when the lights came on. Salyut was alive—alive!"[159]

Dzhanibekov was also glad that the ventilating fans were working again, noting that carbon dioxide build up had made him and Savinykh weary and caused headaches. Communications with ground control were also possible using the Salyut systems at this point. Monitoring of voice communications by the Kettering Group showed that the crew was still using the Soyuz frequencies at 11:16:27 MT on June 12, but that on the next orbit they were transmitting from Salyut (12:46:07 MT).[160]

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[151] Pravda, October 8, 1985, p. 3.
[152] Pravda, August 5, 1985, p. 3.
[153] Kidger, Neville. Salyut Mission Report. Spaceflight, December 1985, p. 470.
[154] Krasnaya Zvezda, October 1, 1985, p. 3.
[155] Perry, G. E. School Science Review (Association for Science Education, England), December 1986, p. 321.
[156] Pravda, August 5, 1985, p. 3.
[157] Krasnaya Zvezda, October 1, 1985, p. 3.
[158] Pravda, August 5, 1985, p. 3.
[159] Dzhanibekov, V. Rescue in Outer Space. Parade, July 27, 1986, p. 13.

The water supply on Salyut had frozen, so they tried to expose the water tanks to sunlight during the sunlit portions of the orbit. They had brought an eight day supply of water with them on Soyuz, but it was not until their 11th day in orbit that the ice began to thaw. "[W]e had all the water we needed. In fact, we had too much, for water began to form on the cold parts of the casings and covered the windows and pipes. We had a lot of mopping up to do with towels, napkins, underwear."

Each of the station's hundreds of cables had to be checked. Dzhanibekov's most telling comment was that "One word best describes all of our repair and maintenance operations—patience. . . . The main thing in such operations is not to give way to nerves, although weariness gradually builds up into irritation—sometimes with yourself, sometimes with those trying to help you from the ground. You simply have to be able to pull yourself together in the face of setbacks and mishaps."

In the end, they determined that a faulty charge-gauging device in one of the chemical batteries had failed, permanently breaking the connection with the solar panels. "This connection would not be restored without power from an outside source. Connecting the spaceship's power plant to the station was ruled out, because this might lead to the breakdown of the ship's own power supply system."[161]

*The Mission Continues*

Once they had rejuvenated Salyut 7, the crew resumed the conduct of experiments and other operations. After determining that the automatic docking systems were functioning correctly, Progress 24 was launched on June 21 at 04:40 MT. It carried 2,000 kg of equipment and supplies, including new solar panels which were installed two weeks later, drinking water, and new chemical batteries.[162] The cargo craft docked with the station on June 23 at 06:54 MT.

By June 25, the crew was performing experiments, starting off with remote sensing observations in the "Kursk-85" program. They continued to unload Progress, and after refueling the space station, it was undocked at 16:28 MT on July 15 and reentered the same day.

The next launch to Salyut was also somewhat of a surprise to Western observers. Cosmos 1669, a Progress variant, but not given the Progress designation, was launched on July 19, and docked with Salyut 7 at 19:05 MT on July 21.[163] Although the launch of a module had been expected, it had been anticipated to be of the much larger Cosmos 1443 class, not a Progress, and the docking announcement was accompanied by the statement that it carried experiments "to conduct scientific research in an autonomous flight and as part of an orbital complex."[164] This led some Western observers to speculate that it was a new class of spacecraft similar to the co-orbiting platforms planned for the U.S. space station program. They suggested that this Cosmos would be separated from the space station and flown autonomously.[165] In fact, it appears that Cosmos 1669 was simply a cargo craft that delivered some biological experiments in addition to the usual complement of fuel, water and other supplies. It undocked at 01:50 MT on August 29 and reentered the following day. TASS did add that "in autonomous flight, tests continued on individual systems and installations of the satellite."[166] Several weeks later the Soviets explained that one activity conducted by Cosmos 1669 after originally undocking from Salyut 7 was a test to confirm the reliability of the docking system in preparation for the launch of the next crew. It backed away from the station and then redocked. It is not clear if the time of 01:50 MT for undocking was the first or second time.[167]

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[160] Perry, G.E. Personal communication.

[161] Pravda, August 5, 1985, p. 3.

[162] Pravda, August 5, 1985, p. 3.

[163] It is unclear why this was not given a Progress designation. Neville Kidger reported in the December 1985 issue of Spaceflight that the Soviet media [illegible] commentaries on July 20 about a docking between the space station and Progress [illegible] speculates that it may have been a matter of a mixup at the TASS office, or early [illegible] threatened the mission and hence a Cosmos designation was deemed necessary (the [illegible] often give failed satellites a Cosmos designation instead of a name, as with the Cosmos [illegible] station launch that failed.)

### *Installing Another Set of Solar Panels*

On August 2, the crew conducted an EVA to install new solar panels on the remaining original array.[168] The five hour EVA began at 11:15 MT. TASS reported that after installing the two new panels, they "installed an experimental model of a solar [panel] for researching the effects of outer space conditions on it."[169] The new panel reportedly was 4.5 meters long and 1.2 meters wide. They then moved back to the exit hatch and retrieved the samples left by the T-12 crew, and replaced them with a Soviet/French device to gather meteoritic dust in connection with observations of Halley's Comet[170] and another *Meduza* experiment.[171] Soviet press reports noted that the space suits used by the crew were improved, with illuminated control units and improved shoulder belts which enable the cosmonauts to expand the area in which they can work outside the station. A sturdier rubberized fabric also replaced part of the rubber shell.[172] Other reports said they had a greater field of vision, allowed greater mobility, and provided for monitoring the crew's health.[173]

## *Soyuz T-14 Launch and First Crew Rotation*

On September 17, 1985 at 16:39 MT, Soyuz T-14 was launched with a three-man crew (call sign Cheget): Lt. Col. Vladimir Vasyutin, commander; Georgiy Grechko, flight engineer; and Lt. Col.

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[164] TASS, 1710 GMT, July 21, 1985.

[165] Kidger, N. Salyut Mission Report. Spaceflight, December 1985, p. 471.

[166] TASS, 0930 GMT, August 30, 1985.

[167] Pravda, September 19, 1985, p. 2.

[168] The T-9 crew had installed the first set of additional panels to one of the three main arrays; the T-10 crew added another set.

[169] TASS, 1411 GMT, August 2, 1985.

[170] Pravda, August 3, 1985, p. 3.

[171] TASS, 1052 GMT, August 9, 1985.

[172] Pravda, August 3, 1985, p. 3.

[173] Kidger, Neville. Salyut Mission Report. Spaceflight, December 1985, p. 471.

Aleksandr Volkov, cosmonaut researcher. This was the third flight for Grechko and the first for Vasyutin and Volkov. The ship docked with Salyut 7 and Soyuz T-13 at 18:15 MT on September 18. At 21:24 they entered the station and were greeted by Dzhanibekov and Savinykh. The docking announcement included the statement that Vasyutin and Volkov would remain on the station with Savinykh, while Dzhanibekov and Grechko would return to Earth,[174] and a week later *Krasnaya Zvezda* reported that the original crew was intended to be Savinykh, Vasyutin and Volkov,[175] but the Salyut 7 problems surfaced during the crew's training, necessitating the rescue mission.

### *Soyuz T-13 Departs and Cosmos 1686 Arrives*

The Soyuz T-13 spacecraft, with Dzhanibekov and Grechko aboard, undocked at 07:58 MT on September 25. The return to Earth was quite unusual in that the crew remained in the Soyuz for a day before landing. The extra day was spent in testing rendezvous methods unaided by radar signals from the station. After undocking, Dzhanibekov fired the T-13 engines to separate the ship from the space station by several tens of kilometers. The T-13 engines were then fired three times to bring it within 5 km of the space station at which point Dzhanibekov and Grechko guided it to within several hundred meters of the station. The experiment reportedly was valuable for refining maneuvers that might be needed "to come to the aid of disabled spacecraft."[176] They finally landed at 13:52 MT on September 26, 220 km northeast of Dzhezkazgan. It was noted that this was a new landing zone for spacecraft.[177] Dzhanibekov had been in space for 112 days 3 hours and 12 minutes; while Grechko's duration was 8 days 21 hours and 13 minutes.

Maintaining their quick pace, no sooner had the T-13 spacecraft returned than a new module was launched. This was a Cosmos 1443-class spacecraft and numbered Cosmos 1686. Launched on September 27, it was the first of the series to lack a reentry capsule and carried extra fuel instead.[178] It carried five tons of supplies (of which 3 tons were fuel)[179] and was heralded by the Soviets for its ability to control the space complex "for hours and even for days" freeing the cosmonauts "from the task of manual control."[180] It also carried one ton of scientific instruments, which by October 30 had been completely tested by the crew.[181] Included were spectrometers for astrophysical observations, and new materials processing equipment. The Soviets stated that Cosmos 1443 had proved its value as a space tug and recovery vehicle, and that Cosmos 1686 was "now being tested as a multifunctional orbital module which can deliver cargo into space, supply the station with power, assume control of the whole complex, and serve as a scientific laboratory or as a production-process 'shop.'"[182] Cosmos 1686 docked with Salyut 7 and Soyuz T-14 on October 2 at 13:16 MT.

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[174] TASS, 1834 GMT, September 18, 1985.

[175] Krasnaya Zvezda, September 28, 1985, p. 4.

[176] Trud, September 27, 1985, p. 3.

[177] Trud, September 27, 1985, p. 3.

[178] Cosmonaut Valeriy Ryumin made this comment at Flight Control Center during a visit by a U.S. congressional delegation of which this author was a member.

[179] TASS, 2300 GMT, October 17, 1985.

[180] Sotsialisticheskaya Industriya, October 3, 1985, p. 4.

[181] Moscow World Service, 1600 GMT, October 30, 1985.

On November 1, *Pravda* reported that Cosmos 1686 was maintaining space station orientation for as long as a week at a time. It was also noted that on a rest day, when precise orientation was not required, Volkov asked that it be maintained anyway because it provided a "normal psychological climate."[183]

### *Vasyutin's Illness Forces Early Mission Termination*

Volkov's interest in maintaining a normal psychological climate became more apparent as time went by. *Aviation Week and Space Technology* reported that beginning November 13, the crew began scrambling their conversations with mission control and incorrectly concluded that it was related to military activity.[184] As soon became clear, the scrambled transmissions were related to a medical emergency on board the station.[185] On November 15, TASS reported that the crew was undergoing medical checks again, a routine announcement except that it contained the tell-tale clue that they were wearing the "Chibis" suits that cosmonauts don prior to returning to Earth's gravity.[186] No further announcement was made until six days later when the crew had returned to Earth. Soyuz T-14 landed 180 kilometers southeast of Dzhezkazgan at 13:31 MT on November 21. Unlike most missions, no announcement was made of the time of undocking, and the return was announced only after the crew was on the ground. Vasyutin and Volkov had been in space for 64 days 21 hours and 52 minutes; Savinykh's duration was 168 days 3 hours and 51 minutes.

The reason for terminating the mission was announced by the Soviets upon the crew's return: the crew's commander, Vasyutin, had become ill and required hospital treatment.[187] Vasyutin's illness was so severe that Savinykh had to assume command of the mission.[188] A Soviet reporter at the landing site commented that Vasyutin was pale, "but they are all generally rather pale after a flight." In response to the reporter's question of how he felt, Vasyutin responded: "The main thing is to be back on Earth."[189] An observer at the landing site, identified only as Aleksey Arkhipovich, commented on Vasyutin's illness and gave an indication of other medical problems that had been encountered by previous crews:

> Nothing comes that easily, everything comes with difficulty every discovery, every intervention into nature's secrets. Well, today we came up against another such fact—that is that the commander of the crew fell ill. Well, one could have expected it. We are happy that this has not happened before—there were cases of toothaches, and some kinds of colic, but what happened this time—a cold going into some new forms, a rise in temperature. This required the urgent intervention from earth, and the taking of the difficult decision to land. Of course, they very much wanted and

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[182] Sotsialisticheskaya Industriya, October 3, 1985, p. 4.

[183] Pravda, November 5, 1985, p. 3.

[184] Soviet Scramble. Aviation Week and Space Technology, November 18, 1985, p. 13.

[185] Space Return, November 25, 1985, p. 13. Transmissions Scrambled for Medical Talk Before Cosmonauts Return. Aerospace Daily, November 25, 1985, p. 124.

[186] TASS, 1547 GMT, November 15, 1987.

[187] TASS, 1144 GMT, November 21, 1985.

[188] Izvestiya, November 22, 1985, p. 6.

[189] Moscow Domestic Service, 1530 GMT, November 21, 1985.

would still like to work, but this is what had to be done, and now one can say that they were right.[190]

Vasyutin was flown directly to Moscow, while Savinykh and Volkov took the usual route back to Tyuratam. There was much speculation about the nature of Vasyutin's illness, and the Soviets have never publicly clarified what was wrong. Western observers speculated that it could be kidney stones or appendicitis,[191] a cold that spread into his sinus cavity and lungs, or viral pneumonia.[192] Despite the commentary by Aleksey Arkhipovich quoted above about "a cold going into some new forms," subsequent descriptions suggested something worse. *Pravda* stated on November 23, two days after the landing, that the problem had worsened over a period of time: "At first he himself as well as his comrades in space and on the ground hoped that the attacks of pain could be overcome."[193] On December 20, when Savinykh and Volkov returned to Star City, Moscow television reported that Vasyutin had left the hospital that day and shed a little more light on the matter, noting that Vasyutin had fought against an "inflammation" for three weeks with "a soaring temperature of up to 40 degrees Celsius" (104 degrees Fahrenheit).[194] This was the first mention of an inflammation, and the report indicated that the problem had developed long before the scrambled transmissions of November 13. A December 29 *Pravda* article went somewhat further through quotes from Savinykh's diary. The article noted that the first entry in the diary concerning the illness was on September 25, the same day Dzhanibekov and Grechko left. The first indications of Vasyutin's illness was "anxiety in his behavior and loss of sleep and appetite. Then pain appeared." An October 28 entry noted that Vasyutin was in bad shape, "tense, a bundle of nerves." It was then that Savinykh and Volkov convinced Vasyutin to consult with ground controllers, which he did, receiving instructions from medical specialists which made him feel better. The entry for November 2, however, indicated that Vasyutin was remaining in his sleeping bag while Savinykh and Volkov carried out the program. Orders to terminate the mission came on November 17.[195]

At the end of 1987, no further details had been released by the Soviets about what had gone wrong. At a meeting of the International Astronautical Federation in Brighton, England in October, 1987, Oleg Gazenko, head of the Soviet Institute for Biomedical Problems and the most prominent Soviet space physician, stated that he would not comment on Vasyutin's illness for reasons of medical ethics, but that Vasyutin was completely recovered.[196]

At a press conference shortly after the landing, Savinykh lamented leaving so much work undone on the station. He noted that they had tested all of the equipment brought by Cosmos 1686 and had prepared proposals for improving that technology and developmerit new equipment. "But much work was left unfinished, and it was therefore with regret that we closed the hatch of the scientific module before our return."[197]

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[190] Moscow Domestic Service, 1530 GMT, November 21, 1985. The reference to the toothache was probably Romanenko on Soyuz 26; the colic reference is unclear.

[191] Soviet Union Ends Space Mission Because of Commander's Illness. New York Times, November 22, 1985, p. A4.

[192] O'Toole, Thomas. Illness That Forced Cosmonaut's Return a Mystery to NASA. Washington Post, November 27, 1985, p. A3.

[193] Pravda, November 23, 1985, p. 3.

[194] Moscow Television Service, 1530 GMT, December 20, 1985.

[195] Pravda, December 29, 1985, p. 3.

[196] Private conversation, October 12, 1987.

The completion of work with Salyut 7 was left to the first crew of the new space station Mir, as recounted in the following chapter.

### 1986 ACTIVITIES

It was not clear at the end of the Soyuz T-14 mission in November 1985 whether Salyut 7 would be occupied again or not. Rumors had been rampant since early 1985 that another Salyut was almost ready for launch, and with the multitude of repairs that had to be performed to keep Salyut 7 operational, it seemed possible that the Soviets would replace it. Nevertheless, the T-14 crew had been unable to fully utilize all the equipment brought by Cosmos 1686, and the module itself was still docked with the space station.

The question appeared to be answered in February 1986 when a new space station, Mir, was launched. While there was some speculation in the West that the Salyut 7/Cosmos 1686 complex would dock with Mir, this seemed less and less likely as time went by and Soyuz T-15 was launched to dock with Mir in March. The Soviets were still full of surprises though, for Soyuz T-15 turned out to be the first crew to occupy two space stations, Mir and Salyut 7. Mir activities are discussed in the next chapter. This section will describe only those Soyuz T-15 activities that were conducted on Salyut 7. Details on experiments can be found in the section entitled "Experiments." Following the departure of the crew, the Soviets announced that Salyut 7 would be placed into a higher orbit where they would monitor deterioration of its systems. This was accomplished, using Cosmos 1686, in August 1986. At the end of 1987, Salyut 7 and Cosmos 1686 remained docked together in this orbit.

#### SOYUZ T-15 AND SALYUT 7: FINAL CREW OPERATIONS

On May 3, the Soviets announced that the Soyuz T-15 crew that had docked with Mir in March would transfer to Salyut 7.[198] Leonid Kizim and Vladimir Solovyev comprised the crew; they had been two of the three members of the 237 day mission on Salyut 7 in 1984. The T-15 spacecraft had been outfitted with a laser rangefinder to permit accurate acquisition of Salyut 7 from a distance of 5 km, and an optical sight and night vision instrument—in effect, what the T-13 crew had installed for the manual docking with Salyut 7 in 1985. Whether this indicated continued problems with the Salyut docking systems is unclear. At the time of the transfer, it was noted that while Salyut 7 was unoccupied, Cosmos 1686 had been performing atmospheric observations in an automated mode, as well as cosmic ray studies.[199]

To accomplish the transfer, Mir's orbit was lowered using the Progress 26 engines.[200] The crew then undocked from Mir at 16:12

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[197] Izvestiya, November 24, 1985, p. 3.
[198] Moscow Television Service, 1700 GMT, May 3, 1986.
[199] Izvestiya, May 7, 1986, p. 2.
[200] Cosmonauts Complete Flight from Mir to Salyut. Aerospace Daily, May 7, 1986, p. 211.

MT on May 5, using springs to separate from the station rather than engines to prevent the solar panels from becoming contaminated with engine exhaust.[201] The space stations were 3,000 km apart when the crew left Mir. After four orbits, the T-15 engines were fired to place the spacecraft into a lower orbit where it would fly faster than Salyut 7 to catch up with it. Then its engines were fired again to go into a higher orbit than Salyut 7,[202] until they were within a few kilometers of each other. Cosmos 1686 was used to rotate Salyut 7 on command from the ground so that the forward docking port would be pointed toward the arriving spacecraft. The docking was done manually from a distance of 5 km,[203] and was achieved on May 6 at 20:58 MT. Orbital parameters for the Salyut 7/Soyuz T-15/Cosmos 1686 complex were 360 x 336 kilometers, 91.2 minutes on May 9.

The Soviets had stated that the crew was taking 500 kg of material to Salyut 7 which had been brought up by Progress 26, but no details were provided on what experiments they were.[204] Once on board, they reactivated the space station and resumed use of experiments that had been used by previous space station crews. Among the first were remote sensing observations and atmospheric studies using ASTRA. Once again, however, they were sidetracked by operational matters. This time it was two EVAs to experiment with the extension of a lattice work girder in a test related to building large space facilities.

### *Two EVAs for Space Construction and a New Laser Communications Device*

The crew performed a 3 hour 50 minute EVA on May 28. This was their seventh EVA together, having performed six in 1984. The hatch was opened at 09:43 MT, and the first task was retrieval of specimens left by previous crews, including Meduza and the Soviet/French comet dust collection experiment. Live television pictures of the EVA were broadcast on Soviet television beginning 1 hour and 46 minutes into the spacewalk.[205] This demonstrated the ever growing confidence the Soviets have in their cosmonauts and the programs they are asked to perform.

The crew's main task was deployment of a hinged metal latticework girder (called Ferma-Postroitel for Constructor-Girder), developed by V. Lapchinsky, developer of Isparitel and the URI tool used by Savitskaya and Dzhanibekov in 1984. First the crew installed a platform next to the hatch. Then they moved the large cylindrical drum that contained the girder out of the station and onto the platform. The girder was folded up inside a 1 meter high by 1 meter in diameter cylinder, the total weight of which was 150 kg (the girder alone weighed 20 kg).[206] They unfolded the 12-meter long girder,[207] then folded it back up again. The test was both of the mechanism for folding and unfolding (called URS), and the principle of erecting structures in space. Lapchinsky commented:

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[201] According to Western analyst Nicholas Johnson, all spacecraft departing from Mir use springs to push away before firing their engines in order to reduce contamination of windows, solar panels, and other exterior devices. (Johnson, N. Soviet Year in Space—1986. Colorado Springs, Colorado, Teledyne Brown Engineering, 1986. p. 59.

[202] Trud, May 7, 1986, p. 4.

[203] Gudok, May 8, 1986, p. 1.

[204] Moscow Television Service, 1700 GMT, May 3, 1986.

[205] Soviet TV Carries Space Project Live. Washington Post, May 29, 1986, p. A27.

[206] Trud, May 29, 1986, p. 3; Moscow Television Service, 0730 GMT, May 28, 1986.

> We are at the threshold of the era of space construction— various telescope mirrors, gigantic solar panels, hangers, and so forth. The length of our girder is still comparatively short. But the mechanism of a girder-assembly aggregate will make it possible, by loading it with more and more folded cassettes, to build a 'mast' a kilometer long and even more. In addition, it is important for us to know how such a hinged lattice-work structure behaves in zero gravity.[208]

The Soviets also reported that the crew installed on one of Salyut's windows "a new instrument which is intended for experiments for perfecting a future system for transmitting telemetry information in the optical band of wavelengths."[209] Called BOSS, it was developed by Professor B. V. Batalov to enable transmission of data from instruments on the girder to the space station and then to the ground with a minimum number of wires. Signals received by the optical device on the window were converted into digital form and then transmitted via a low power (3 milliwatt) laser through the glass where they struck the BOSS receiving unit located inside the station. There the light pulses were converted back into electric signals for digital transmission to Earth. The unit had triple redundancy in its main assemblies to improve reliability.[210]

A second spacewalk commenced at 08:57 MT on May 31 and lasted five hours. It also was broadcast live on television. The girder was again erected and two instruments mounted on it: the "Fon" (Background) instrument for measuring the atmosphere around the structure, and a device to monitor the vibrations of the frame. The crew had some difficulty extending the frame on the second EVA, but ultimately succeeded. Kizim "climbed" the frame like a stepladder, commenting that it rocked, but was firm.[211] They then refolded the girder, with the experiments remaining in place.

Next, the crew used an improved version of the URI instrument tested by Savitskaya and Dzhanibekov in 1984 to weld lattice and pin structures (they were separate from the girder, since this was just for experimental purposes). It was noted that the URI device had been modified based on Dzhanibekov's and Savitskaya's experience and was now easier to operate.[212] The cosmonauts also installed a "microdeformator" to operate "permanently there in space with samples which it will stretch, squeeze, and so on; in other words it will test the properties of the material, its strength characteristics. And via the cable laid across the surface—that was done during the previous space walk—all this will be transmitted to the station, and then to Earth. What we are really doing now is rehearsing the rudiments of future construction in space. We are mastering it."[213] At the end of these two EVAs, Kizim and Solovyev had each spent 31 hours and 40 minutes performing spacewalks together.

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[207] There is conflicting information from the Soviets about the length of the extended girder. On May 31 (1359 GMT), TASS stated that it was 12 meters long. Earlier, however, Moscow Television Service (0730 GMT, May 28, 1986) and TASS itself (0730 GMT on May 28, 1986) reported that the girder was 15 meters long. In a paper for the 1987 International Astronautical Federation conference, Solovyev himself said it was 12 meters long (IAF paper 87-77, p. 4). Since he actually deployed the girder, his statement is used here.

[208] Pravda, May 29, 1986, p. 1.

[209] Pravda, May 29, 1986, p. 1.

[210] Trud, June 1, 1986, p. 2; Pravda, June 1, 1986, p. 6.

[211] Moscow Domestic Service, 0800 GMT, May 31, 1986.

[212] Pravda, August 16, 1986, p. 3.

### *Experiments Resume Inside the Station*

Following their two spacewalks, the cosmonauts settled down to working with experiments inside the space station again, as well as some they left on the outside. On June 6, it was reported that they were conducting remote sensing observations, atmospheric studies, and the experiments with the microdeformator on the outside of the station. *Biogravistat* experiments with lettuce seeds resumed, as well as the *Mariya* experiment related to measuring cosmic rays in the space station. They also worked with the KRISTALLIZATOR materials processing device brought to Salyut 7 by Cosmos 1686. Few details were provided of these experiments.

Although the Soviets soon indicated that Salyut 7 would not be occupied again, the crew performed repair work on the station, servicing the thermal regulation system on June 20, for example.

### *The Return to Mir and the Future of Salyut 7*

On June 23, the Soviets announced that Kizim and Solovyev would leave Salyut 7 on June 25, taking with them some of the scientific equipment as well as the results of the experiments they had performed. A total of 400 kg of equipment and instruments [214] were transferred to Mir (100 kg less than they had taken to Salyut 7). Included were the KATE-140 camera, the EFU-Robot electrophoresis experiment, the ultrasonic cardiograph, the French PSN astrophysics and atmospheric device, and the Pion-M heat transfer experiment.[215]

Soyuz T-15 undocked at 18:58 MT on June 25. The stations were still 3,000 km apart, but Mir was now 25-30 km above Salyut 7. At that point, Soyuz T-15 had 420 kg of fuel remaining, of which 250 kg were needed for returning to Earth, so the orbit chosen for returning to Mir was designed for economical fuel consumption, rather than the shortest route.[216]

On June 21, an orbital correction had been made for Mir using Progress 26, and on June 23 Progress 26 undocked from Mir, leaving all of Mir's ports free. It was announced that when Soyuz T-15 was within 100 meters of Mir, the space station would be rotated so that the front docking port would be in position for docking, but that the crew would have to assume manual control for docking at 50 meters because the "Igla" system "with which the ship will interact, is not located on the docking port of the station where Soyuz T-15 will dock."[217] Docking was achieved at 23:46 MT on June 26.

Cosmonaut Kubasov commented on the importance of inter-orbit operations, especially the fact that they were made almost entirely automatically.

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[213] Moscow Domestic Service, 0800 GMT, May 31, 1986.
[214] Komsomolskaya Pravda, June 28, 1986, p. 4.
[215] Pravda, June 28, 1986, p. 6.
[216] Komsomolskaya Pravda, June 28, 1986, p. 4.
[217] Izvestiya, June 27, 1986.

> In principle, however, [Soyuz T-15's] entire flight could have been made in the automatic mode. You can imagine how important it will be to have such an automatic ferry for future space complexes. These transport ferries could fly, for example, between residential and industrial zones of a space colony, or between various modules and extraterrestrial observatories. Moreover, a ferry could, if necessary, be sent from one space base to another as a means of rescuing cosmonauts if their spaceship broke down. . . .[218]

TASS reported on August 16 that Salyut 7's "work in the manned regime was fulfilled."[219]

On August 23, the space station was moved into a 492 x 474 km orbit using Cosmos 1686.[220] Two weeks later, an article by space station designer Yu. Semenov reviewed what had been accomplished on Salyut 7, noting that its role as a base for crew activities was over, but left open the possibility that it might be visited again some years in the future to retrieve samples of materials on the station. He said that a "rendezvous" was possible, but did not specifically say a docking. In the meantime, its telemetry would be monitored to study its systems and how they deteriorated over time, including the "reliability of design solutions relative to the airtight-sealing of living compartments, tanks and lines that carry fluids and air." The dynamics of its orbital decay pattern were also of interest. Semenov added that its lifetime would be "at least eight years" although it was not clear if that included the five years it had already spent in orbit, or was an additional eight years. He concluded:

> It is possible that after several years, an inspection expedition may be sent up to the complex to rendezvous with it. The expedition will make studies of the condition of the structure and equipment of the complex, and it will dismantle separate fragments of structures, cables and solar panels, as well as some of the instruments, and bring them to Earth.
>
> As a result it will be possible to gather data on the meteor situation, the condition of photocells of solar panels, the sturdiness of structural materials, processes in nonmetallic materials, and other things.
>
> With the completion of the research program, the return of the station to a designated region on Earth will be organized.[221]

TABLE 7.—CREWS SENT TO SALYUT 7: 1984–86

| Mission | Launch date | Reentry date | Duration | Comments |
|---|---|---|---|---|
| Soyuz T-10/T-11 | 02/08/84 | 10/02/84 | 237 days | Main crew. New duration record. |
| Soyuz T-11/T-10 | 04/03/84 | 04/11/84 | 8 days | International visiting crew (India). |
| Soyuz T-12 | 07/17/84 | 07/29/84 | 12 days | Savitskaya became the first woman to make a spacewalk. |
| Soyuz T-13/T-14 | 06/06/85 | 09/26/85 [1] | See comments | First crew rotation; partial replacement of crew. Dzhanibekov and Savinykh were launched on Soyuz T-13. Dzhanibekov returned on the T-13 craft with Grechko from Soyuz T-14. Duration for Dzhanibekov was 112 days. Savinykh remained onboard with two crew from Soyuz T-14. Savinykh duration was 168 days. |

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[218] Trud, June 28, 1986, p. 3.
[219] TASS, 1332 GMT, August 16, 1986.
[220] TASS, 1121 GMT, August 23, 1986.
[221] Pravda, September 8, 1986, p. 7.

## TABLE 7.—CREWS SENT TO SALYUT 7: 1984–86—Continued

| Mission | Launch date | Reentry date | Duration | Comments |
|---|---|---|---|---|
| Soyuz T–14/T–13 | 09/17/85 | 11/21/85 [1] | See comments | Vasyutin and Volkov were launched on T–14 with Grechko, and remained on board with Savinykh from T–13. Mission ended prematurely when Vasyutin became ill. Duration for Vasyutin and Volkov was 64 days. Duration for Grechko was 8 days. |
| Soyuz T–15 [2] | 03/13/86 | See comments | See comments | Soyuz T–15 docked first with Mir. Crew taxied to Salyut 7 and were aboard from 05/06/86 to 06/25/86 before returning to Mir. |

[1] Reflects reentry of ship, since crew rotation aspects make it impossible to have a single crew duration. However, the T–13 ship duration was the same as Dzhanibekov's duration; and the T–14 ship duration was the same as Vasyutin's and Volkov's. Dates reflect Greenwich Mean Time.

[2] Spacecraft first docked with Mir, then "taxied" to Salyut 7.

Prepared by Marcia S. Smith, CRS.

## TABLE 8.—CARGO AND MODULE FLIGHTS TO SALYUT 7: 1984–86

| Mission | Launch date | Reentry date | Duration | Comments |
|---|---|---|---|---|
| Progress 19 | 02/21/84 | 04/01/84 | 39 days | 35 days docked. |
| Progress 20 | 04/15/84 | 05/07/84 | 22 days | 19 days docked |
| Progress 21 | 05/08/84 | 05/26/84 | 18 days | 16 days docked. |
| Progress 22 | 05/28/84 | 07/15/84 | 47 days | 45 days docked. |
| Progress 23 | 08/14/84 | 08/28/84 | 14 days | 10 days docked. |
| Progress 24 | 06/21/85 | 07/15/85 | 41 days | 39 days docked. |
| Cosmos 1669 |  |  |  | Progress-class mission. Unclear why it was not given a Progress name. |
| Cosmos 1686 | 09/27/85 | Still docked |  | Cosmos 1443–class module. Brought equipment and fuel. Remains docked with Salyut 7. |

Prepared by Marcia S. Smith, CRS.

Dates reflect Greenwich Mean Time.

## CHAPTER 3—MIR: 1986-87

On February 20, 1986,[1] the Soviets launched a third-generation space station called Mir (Peace). The name of the space station could equally as well have been Salyut 8, since the major differences between it and its predecessors were the addition of a docking collar with four additional docking ports, and greater use of computers. The Soviets, however, were proclaiming a "Star Peace" proposal in reaction to the U.S. "Star Wars" Strategic Defense Initiative, and the use of the name Peace for their new space station was part of their attempt to portray their space program as entirely peaceful. At the time of the launch, Cosmonaut Aleksey Leonov, deputy director of the Gagarin Cosmonaut Training Center, said: "By naming the space station in this way, we want to emphasize once again that the Soviet programme for space research and for the use of outer space is intended solely for peaceful purposes."[2]

The impending launch of the new space station was announced in a Prague news dispatch (in English) on January 27, 1986 citing a speech by Cosmonaut Vitaliy Sevastyanov.[3] When it was launched on February 20, the accompanying press announcement stated that it was "in honor of the 27th Congress of the Communist Party of the Soviet Union" and represented "a new stride in the exploration of outer space."[4] Soviet press were on hand at the Flight Control Center outside Moscow for the launch, and Cosmonaut Savinykh, who had closed the hatch to Salyut 7 only three months earlier, commented that use of Mir would involve "power engineering, natural resource study, technological, astrophysical, biological and other modules."[5] Cosmonaut Vladimir Dzhanibekov stated that Mir's lifetime was planned for five years "and perhaps even longer."[6]

### DESIGN

As noted, Mir is much the same as Salyut in basic design. The major improvement is that it has six, rather than two docking ports. This permits the Soviets to move scientific equipment into the modules, at once permitting them to increase the portion of the space station devoted to living and operations, and to change scientific modules as research directions change. The name Mir refers to the core of the station; the scientific modules have their own names (the first one is called Kvant and is discussed under the section on Soyuz TM-2 and TM-3).

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[1] February 20 Moscow Time; it was February 19 GMT (Greenwich Mean Time).
[2] TASS, 2342 GMT, February 19, 1986.
[3] Prague CTK, 1326 GMT, January 27, 1986.
[4] Vechernyaya Moskva, February 20, 1986, p. 1.
[5] Ibid.
[6] Moscow Domestic Service, 1600 GMT, March 15, 1986.

The Soviets gave a rather complete, albeit general, description of Mir at the 1986 and 1987 meetings of the International Astronautical Federation. Except as otherwise noted, the information in this section is from the IAF papers.[7]

### MIR DIMENSIONS AND BASIC CONTROL SYSTEMS

The dimensions of Mir are much the same as Salyut: a cylinder 13.13 meters long (slightly shorter than Salyut because of the changes to the transfer tunnel/docking collar) and 4.2 meters in diameter. Its mass is 21 metric tons (slightly more than Salyut). When launched, Mir had two solar panels, but a third was added in June 1987 (see "electrical supply"). A pointing accuracy of 1.5 degrees (rough) or 15 minutes (precise) can be attained using the stabilization systems (some of the astrophysical instruments can attain greater accuracy using their own systems in addition).

Mir has greater space-worthiness than Salyut, relying heavily on its own computers and able to process scientific data before relaying them to Earth.[8] It is designed for greater fuel efficiency, using solar-electric powered gyroscopes for some of the attitude control maneuvers. As a portent of the ultimate size that the Mir complex can reach, when docked with Soyuz TM-2, Kvant, and Progress 30, it was 35 meters long, weighed 51 metric tons, and had an interior space of 150 cubic meters. To move from one end of the complex to the other required passing through nine hatchway doors.[9] Mir is designed to permit quick refits and replacements of equipment, according to Cosmonaut Sevastyanov, so that "practically every unit is replaceable. This is going to add assembly and construction to cosmonaut's normal duties as researchers and experimenters. Actually, some crews will be responsible for such new operations only. Their job will consist of preparing the station for various scientific missions."[10]

#### *Communications*

Communications between Mir and the Flight Control Center can be routed through communications satellites using Luch transponders (discussed in more detail in Part II of this report). The first Luch was on Cosmos 1700. This is an important feature for Mir since its greater automation requires more communications with the ground. *Izvestiya* noted that on one orbit, 100 commands must be transmitted to Salyut 7, but three times that many are needed for Mir. "When the station becomes occupied with scientific modules, the number will grow to 1,000. Thanks to the new equipment of the tracking stations, the volume of information transmission has increased by approximately 10 times."[11] It is not clear, however, how successful the Luch system has been. Western sources reported that at the end of 1986, the Cosmos 1700 satellite was drifting off station "and its operability is now in question."[12] A new satellite was launched late in 1987.

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[7] Semenov, Y. and Legostayev, V.P. Some Aspects of the Salyut 7/MIR Station Operations. Presented to the 37th Congress of the International Astronautical Federation, Innsbruck, Austria, October 1986. IAF-86-41.

Solovyev, V.A. Man in Space. Presented to the 38th Congress of the International Astronautical Federation, Brighton, England, October 1987. IAF-87-77.

[8] Moscow in English to North America, March 8, 1986 (in FBIS, March 13, 1986).

[9] Gudok, June 16, 1987, p. 4.

[10] Moscow in English to North America, op. cit.

[11] Izvestiya, March 31, 1986, p. 3.

*Windows*

A small but important change is that Mir's windows have covers to prevent formation of residues from exhaust gases of the orbital correction engines.[13] The use of solar-electric powered gyroscopes for attitude orientation also lessens the "pollution" around the space station by requiring less use of the orbital maneuvering engines.

*Computers*

The station uses eight computers for operating all onboard systems, displaying information to the crew, and attitude control. The program for service and experiments for several days at a time can be uploaded from the Flight Control Center directly to the onboard computer system, called *Strela* (Arrow). The crew can update the program if necessary. Leonid Kizim, a member of the first crew on Mir, noted that since missions were getting longer and the flight program more complicated, the amount of information the crew had to deal with had increased considerably.[14] The Strela system can store instructions and procedures for easy access by the crew, as well as access sensors on the space station, assess their status, and display the information on screens. Solovyev noted that the system had been designed at the suggestion of the cosmonauts and that Nikolay Rukavishnikov, in particular, was instrumental in its construction.[15]

*Docking Ports*

The main change accomplished with the Mir design is increasing the number of docking ports to six. Unlike Salyut 6 and 7 which had two ports, forward and aft, Mir has a four-port docking collar at the forward end in addition to the forward port itself. Through the end of 1987, only the forward and aft ports had been used, however.

When the ports at the docking collar are utilized, the arriving module will dock first at the forward port and then use a grappling device to "swing around" to one of the four circumferential ports. The manipulator device for accomplishing the side docking will be carried on the module rather than being part of the Mir space station. Kvant, the first scientific module, apparently is an exception in that it docked with the aft port rather than at a side port. Kvant has two docking ports itself; the one that attaches it to Mir, and one on the other side to which Progress and Soyuz spacecraft can dock.

The Mir docking system itself is new and was designed to reduce fuel consumption of the space station. Called Kurs, it was tested with the automated Soyuz TM mission in 1986 which flew around and docked without directional stationkeeping by Mir. Further information on Kurs is contained in the section on Soyuz TM.

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[12] Johnson, N. Soviet Year in Space--1986. Colorado Springs, Colorado, Teledyne Brown Engineering, 1987. p. 56.

[13] Sotsialisticheskaya Industriya, February 21, 1986, p. 3.

[14] Moscow Television Service, 1700 GMT, July 2, 1986.

[15] Moscow Television Service, 0655 GMT, August 1, 1986.

### *Electrical Supply*

When launched, Mir only had two solar arrays instead of three as is typical for Soviet space stations. A third array was added by the Soyuz TM-2/TM-3 crew in 1987. The third array may have been left off at launch because of weight considerations. The original two arrays are longer than previous versions and undoubtedly added to the mass of the station. In addition, the docking collar added mass to the station, taxing the capability of the Proton launch vehicle.

The original two arrays had a total effective area of 76 square meters and span 29.73 meters. The Mir power supply is a 28.6 volt d.c. system. At the 1986 IAF conference, the Soviets stated that the two arrays generated 10 kw of electricity. At the time the third array was added, however, the Soviets reported that the original two arrays were generating 9 kw, and that the new array, with an effective area of 24 square meters, added 2.4 kw of electrical power.[16] Whether the original arrays had degraded over the year in orbit so that they were generating less, or whether the Soviets had rounded off 9 to 10 in their IAF presentation, is unclear. At the 1987 IAF conference, the issue was further confused when the Soviets reported that Mir's solar panel span was 30 meters with an effective area of 76 square meters—suggesting that they were not counting the addition—with a maximum power supply of 11 kw—a figure that must include the addition.[17] Based on their other reports, the effective area should be 100 square meters, generating 11.4 kw.

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[16] Gudok, June 16, 1987, p. 4.

[17] Semenov, Y.P. The Beginning of the Mir Station Active Operation. Paper presented to the 38th Congress of the International Astronautical Federation, October 10-17, 1987, Brighton, England. IAF-87-84.

FIGURE 1

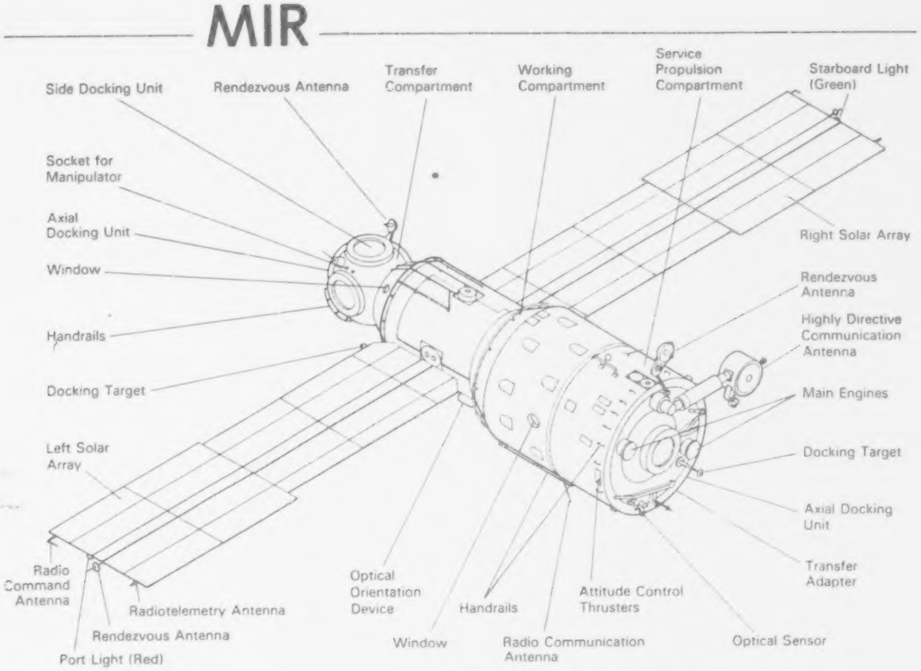
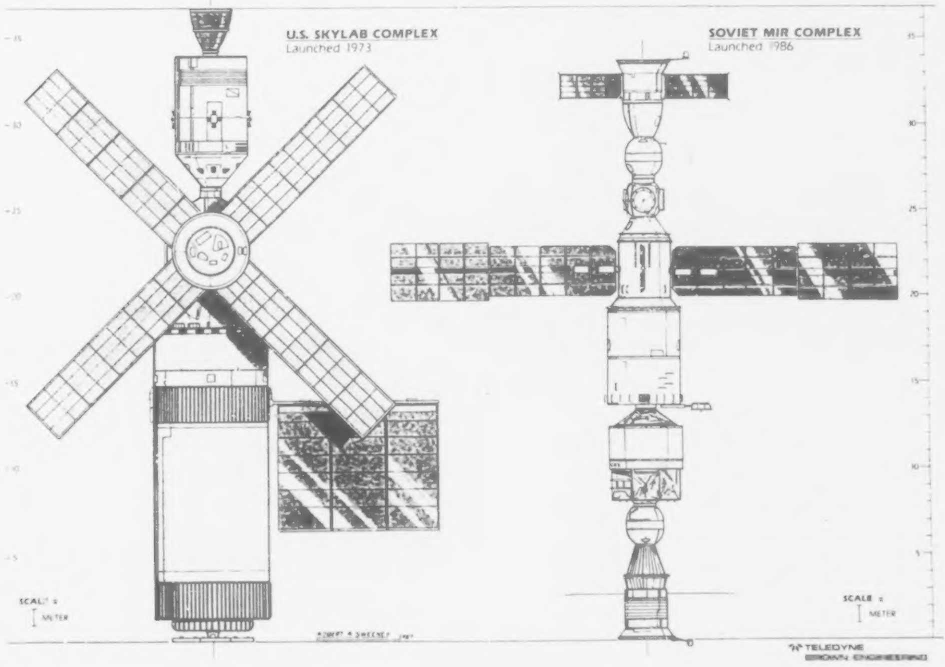


FIGURE 2



Another confusing aspect of the electricity supply issue concerns whether the Mir solar panels are made of silicon or gallium arsenide. The Soviets had added gallium arsenide solar panels to Salyut 7 in 1984, but at both the 1986 and 1987 IAF conferences, they strongly insisted that the Mir solar panels are silicon.[18] Shortly after Mir was launched, however, an article in *Ekonomicheskaya Gazeta* stated that Mir's "power-to-weight ratio is substantially larger" because the "area of the station's solar batteries was increased from 51 to 76 square meters, and the efficiency of their solar-radiation converters was heightened by installing new types of solar cells, particularly ones made of gallium arsenide." It is unclear as to why there is a discrepancy in what the Soviets are saying and what they are publishing, and which version is correct must be considered unresolved.

## MIR'S INTERIOR

Beginning at the forward end of the station and working back through to the engine compartment, the following description of Mir's interior was provided in presentations at the IAF conferences.

### *A Tour*

Mir's transfer module is different from those on Salyut since it is now the sphere with 5 docking units. It serves as a lobby for spacecraft docking and houses the airlock for egress into space. Next are the working and crew compartments: the working module is where equipment is located and the crews perform their work. Near the hatch between the transfer module and the work compartment is the main control post with panels containing sets of displays on the status of onboard equipment. Service system instruments and units are located behind the interior panels.

Next is the crew compartment where individual cabins are provided for two cosmonauts. Each cabin has a window, a sleeping bag, an arm- chair and a desk. In the middle of this compartment is a dining table. The table has been made more comfortable and has two food warmers and moveable chairs that can be fixed in different positions.[19] There also is a repair shop containing tools specially developed for EVA, including hammers that do not rebound, screw- drivers with screw captures, and special drills.

A lavatory and washing device are provided near the hatch connecting the working module with the intermediate chamber, where Mir's aft docking unit is located.

Mir's volume is 90 cubic meters; "Habitable volume is essentially less. It changes depending on the equipment to be delivered to the station." It will increase with the addition of new modules.

The private sleeping compartments provide the crew with a certain amount of privacy in response to complaints from the cosmonauts. Further information on the interior of Mir was published in an article in the U.S. magazine *Space World* by Tim Furniss, although sources were not given for the information.[20] According to the article, Mir's interior is painted in soft pastel colors and work surfaces are easily washable. The crews cook on a hot plate, and are allowed to select their own food as long as they consume the required number of calories. The toilet operates by suction: solid waste is stored in a tank that can be loaded into a Progress cargo ship for disposal and there is a urine receptacle that passes liquid waste into a tank for venting into space. Furniss says there is no shower on Mir, but just a shower head inside a transparent hood into which cosmonauts place their head and hands, and that wet wipes are used to clean other areas of the body. A model of Mir at the 1987 Paris Air Show, however, showed a shower similar to those on the Salyut space stations.

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[18] Statement by Soviet officials at sessions of the IAF in Innsbruck, Austria October 1986 and Brighton, England October 1987. Personal observation.

[19] Sotsialisticheskaya Industriya, February 21, 1986, p. 3.; TASS, 2343 GMT, February 19, 1986.

### *Life Support*

Mir's internal atmosphere is similar to that of previous stations with a pressure of 800–970 mm of Hg and atmospheric composition like Earth's. A greater range of temperatures is allowed though, from 18–28 degrees C; and relative humidity ranges from 30–70 percent.

The station uses a common gas exchange system supported with fans. As additional modules are connected, the gas exchange will be carried out with special air ducts. Gas circulation in the instruments' bay removes heat from operating equipment.

A few changes were made in the life support system to reduce the need for Progress cargo flights. Oxygen for enriching the station's atmosphere is now provided by the *Electron* device on the Kvant module through water electrolytic decomposition. There is also a new system for carbon dioxide removal. Reusable absorbers were used on Salyut, but Mir uses the *Vozduyk* system to absorb and remove carbon dioxide directly into space.

## FUTURE MODULES

As discussed in the section on Soyuz TM-2/TM-3, the first scientific module to dock with Mir was Kvant. By the end of 1987, no additional modules had been launched, and the Soviets stated at the 1987 IAF conference that the next module would not be ready until the end of 1988 or the beginning of 1989.

The modules may be docked with Mir for varying periods of time. Cosmonaut Sevastyanov commented on March 8, 1986 that one advantage of the Mir design is that modules for astronomical, biological and technological research could be separated from the station and "put into mothballs right in orbit for a period of time. When necessary they can be reactivated."[21]

Y.A. Ilyin, an official of the Soviet Ministry of Health, stated in 1987 that one of the future modules would be called "medilab" and dedicated to medical/biological research and could be used to test surgical procedures.[22]

Academician Boris Raushenbakh commented on why the building block approach to space stations was preferable to building one large station. He noted that big space stations are not sufficiently maneuverable to accommodate experiments for looking at the universe and at Earth, and that radiation from equipment and crew movements create obstacles to experiments like those of producing pure substances and growing bacterial cultures. Thus, he added, the modules can be designed to operate with preset programs and dock with the space station only occasionally so crews could collect what had been produced, check the instruments, and recharge energy systems.[23]

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[20] Furniss, T. Inside Mir. Space World, May 1987, pp. 24–25.
[21] Moscow in English to North America, op. cit.
[22] Quoted in Space Commerce Bulletin, July 3, 1987, p. 10.

## EXPERIMENTS

The advantage of the Mir modular design is that it can serve as a more flexible research facility in orbit. Specialized modules for remote sensing, astrophysics, medical/biological studies, and materials processing can be docked with the space station for varying periods of time. Although Western observers at first assumed that the Soviets would quickly launch modules to dock with Mir, this has not proven to be the case. During the period of time covered by this report, only one module, Kvant for astrophysical observations, docked with the space station.

Since Mir itself is not outfitted with scientific equipment, this meant that relatively few experiments were conducted at first. The Soyuz T-15 crew spent its time activating the Mir station. The only experiments the crew performed were during their visit to Salyut 7, or with equipment brought back from Salyut 7 when they briefly returned to Mir. The Soyuz TM-2 and TM-3 crews conducted a modest number of experiments when they first arrived at Mir, but the real scientific program did not begin until June when they had completed checking out the Kvant module and its gyroscopic stabilization systems.

Some of the persistent equipment problems surfaced during a press conference with the Soyuz TM-2 and TM-3 crews just one month later. Aleksandr Laveikin, who was in the process of being replaced on the long duration mission because of cardiac abnormalities, was asked if he had any suggestions for designers of equipment for the space station. He replied:

> We ask that designers pay more attention to questions of reliability. It is very annoying when minor malfunctions and defects are discovered in research equipment during work. We eliminate them ourselves, of course, but the time is lost. We would also like to have more apparatus that operates in the automatic and semiautomatic modes. The more experiments could be conducted simultaneously. The crew's work efficiency would be heightened.[24]

### MATERIALS PROCESSING AND OTHER MATERIALS SCIENCE

Progress in developing a space processing industry was discussed by several Soviet scientists in 1986 and 1987. They could be said to be guardedly optimistic about the near term potential of space processing, and bullish on the long term potential.

Prof. L. Leskov, one of the directors of the Pion research (see below), talked in general about the success of space-based materials processing experiments in March 1987. He said that although some experiments have shown that specimens of inorganic material can be obtained in zero gravity whose properties are better than on Earth, "in certain cases these properties have turned out to be worse than in earth-obtained specimens."[25] This is why he and his colleagues developed the Pion unit to develop an understanding of the dynamics of the process of heat and mass transfer and of crystallization. As for when there would be industrial production of products in space, he estimated that "this frontier will be crossed about 1990."[26]

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[23] TASS, 0941 GMT, March 26, 1986.

[24] Trud, July 29, 1987, p. 4.

Candidate of Technical Sciences Ye. Markov noted in March 1987 that cadmium sulfate crystals obtained on Salyut 7 had been used in laser screens for projection television. "You may be sure that we would never have obtained the quality we did if it hadn't been for space" according to Markov. He went on to say that although spaceflight was expensive, it paid for itself. "The number of usable crystals per wafer grown in space is 10 times greater than the number obtained on Earth. Profit per wafer is 1,900 rubles for "space' ones. Isn't that convincing?"[27]

In June 1987, Alexandr Dunayev, head of Glavkosmos, commented that pilot production experiments would be carried out at the end of "this five year period, and we can seriously talk about pilot production in the next 5-year period."[28] Three months later Moscow World Service reported that "Soviet technology to obtain super pure pharmaceuticals and biological substances in zero gravity had practically reached industrial level." The report added that some of the product of electrophoresis experiments brought back to Earth in July 1987 by the TM-3/TM-2 crew was supplied to centers in Moscow and Leningrad for making flu vaccines.[29]

*Pion-M (Heat and Mass Transfer)*

Prof. Leskov commented that thermocapillary convection "detract[ed] from the properties of materials obtained" in earlier furnaces (Splav and Kristall), and one of their disadvantages was that they were closed so that the "dynamics of phenomena occurring in them could not be observed." Thus Pion was created with a "transparent tray that contains a model liquid through which a beam of light can pass. Non-uniformities distort the light beams" and film can record how the density of the medium changes during the course of an experiment. Particles are sprinkled in, and "in bright light they sparkle like sequins" and the movement of the particles can be traced. Pion experiments started in 1981: "Since then a substantial amount of material for analysis has been accumulated. But space always holds new surprises and presents scientists with new riddles to figure out."[30]

The Soyuz TM-2/TM-3 crew started Pion-M experiments almost immediately after activating Mir in 1987; the Pion unit had been brought to Mir from Salyut 7. On March 6, they conducted the

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[25] Moscow Domestic Service, 0800 GMT, March 12, 1987.
[26] Moscow Domestic Service, 0800 GMT, March 12, 1987.
[27] Komsomolskaya Pravda, March 26, 1987, p. 2.
[28] Moscow Domestic Service, 1530 GMT, June 27, 1987.
[29] Moscow World Service, 0700 GMT, September 23, 1987.
[30] Sotsialisticheskaya Industriya, March 7, 1987, p. 1.

*Vikhr* (Whirlwind) series of experiments to study thermal capillary convection.[31]

Another series of experiments were conducted under the name *Kolosok* by the TM-2/TM-3 crew for studying the formation of aerosols and hydrosols in microgravity. The experiments were developed through the Soviet Academy of Sciences Institute of Physical Chemistry and were relatively simple, according to Leskov, who noted that all that was needed to be done was to shake a test tube and see how particles cling together. In the future, however, the experiments will use "precisely calculated ultrasonic pulses to produce measured effects at certain frequencies and intensities and in certain directions."[32] Leskov marveled at the success of the experiments early in the mission:

> Some of the results are amazing. In the ampoule with the air and particles of fluoroplastic-3, which are the size of a micrometer, for example, these particles banded together in such a way as to make the air pockets under glass look surprisingly like trees. And in the ampoules with an aerosol mix of the air and particles of aerosil (a glass variety) there have appeared a kind of 'flying saucers.' Some of these formations are unexpectedly strong, so strong in fact they cannot be broken even by a one-gram piece of steel contained in the ampoule. I think that these new experiments * * * have moved us into a yet unexplored field of colloidal chemistry.[33]

The aerosil apparently referred to silica aerogel, and it was also noted that glass pellets gathered into solid clumps.[34]

### *Korund-1M (Materials Processing)*

The Soyuz TM-2/TM-3 crew used the improved Korund-1M (Corundum) device. It was delivered by Progress 28 and can operate with six specimens in sequence.[35] It is larger than its predecessors, weighing 136 kg, and was referred to as a "pilot-scale unit" instead of a research unit. It has a built in minicomputer so experiments can be conducted automatically. Temperature can be varied from 20 to 1270 degrees Centigrade and held steady within one-half of a degree. Experiments can last from 6 to 150 hours. Korund's output can be measured in kilograms of semiconductor materials. "Materials produced in the Korund are to be used in electronics and in infrared and laser equipment."[36]

Ye. Markov noted that single crystals of cadmium selenide and indium antimonide produced with the first version of Korund on Salyut 7 had properties close to desired ones, and therefore those experiments would continue with the new Korund unit.[37] He added that the Soyuz TM-2/TM-3 crew would perform "exactly 48 experiments" involving "such rare and extremely valuable semiconductors as cadmium sulfide, zinc oxide, and gallium arsenide." When asked when they would proceed to industrial production, Markov answered:

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[31] TASS, 1120 GMT, March 6, 1987; TASS, 1846 GMT, March 6, 1987.

[32] Komsomolskaya Pravda, March 7, 1987, p. 2.

[33] TASS, 1846 GMT, March 6, 1987.

[34] Sotsialistcheskaya Industriya, March 7, 1987, p. 1.

[35] TASS, 110 GMT, March 13, 1987. Apparently the Korund device delivered to Salyut 7 and barely used was not transferred to Mir with the other equipment.

[36] Pravda, March 17, 1987, p. 6.

[37] Pravda, March 17, 1987, p. 6.

> By 1995, we hope to be able to obtain semiconductor materials for various purposes in amounts of 30–35 kilograms. These materials will be used in superhigh-speed and superlarge integrated circuits, in infrared and laser technology, in photocells for orbiting station's solar panels, and even for needs of medicine, which is waiting for sensitive infrared imagers, for example. Let me emphasize that this is a high priority direction for the advancement of Soviet science, and we are not running second to anyone here.[38]

It was noted that there were initial problems with Korund on Mir: "during tests when the installation was switched on it turned out that one of the units was heating up from the air being emitted from the furnace. But once a protective screen and an air duct were installed the apparatus began to work perfectly."[39]

Later in the mission, Markov noted that they were also working with silicon and gallium arsenide in an attempt to master the basic technology for producing crystals in space. "Gallium arsenide, in particular, will be used for creating radiation-stable ultrahigh-speed integrated circuits, with the view of applying them in mini - and microcomputers for space communication systems in future interplanetary flights, and for mini -and microcomputers of very high speed."[40] The second group of materials being studied in Korund are cadmium sulphide and selenide for use in electronically excited lasers for projection television systems. The third group of materials, at an earlier stage of experimentation than those mentioned previously, involves obtaining materials in the form of tapes "which allows us to skip some individual operations in preparing some semiconducting materials. Cutting, grinding and polishing, which waste about 50 percent of these semiconductors, are made unnecessary * * * ."[41]

*Kristillizator (Materials Processing)*

The Kristillizator device was mentioned for the first time in July 1987 when it was announced that the crew was assembling it and were about to turn it on to obtain temperature pattern characteristics. This step may have been related to their earlier experience with Korund where they discovered that it was being heated by waste heat rejected during the experiments. Kristillizator can process 19 different specimens, from glass to semiconductors, at the same time, with temperatures up to 1,000 degrees. Individual temperature and pressure conditions and rate of movement through the unit are maintained for each specimen.[42]

Experiments using the Kristillizator were part of the program during the visit of the Syrian cosmonaut. The *Palmira* experiment was for growing crystals from water solution, and involved two medical syringes connected by a plastic tube with a clamp from a dropper. The syringes were filled with solutions of different concentrations on Earth; in space the clamp was opened so they could mix by punching down the plungers of the syringes. "The superpure solutions were prepared using nuclear filters that were made in academician G. Flerov's laboratory of nuclear reactions at the Joint Institute for Nuclear Research."[43] TASS reported that the experiment was related to a desire to develop a synthetic bone and tooth tissue. The experiment was designed to obtain structures from numerous monocrystals when they come close together and merge in microgravity. The initial materials for this experiment were hydroxylapatit (which forms the basis of bone and tooth tissue) and gypsum.[44]

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[38] Komsomolskaya Pravda, March 26, 1987, p. 2.

[39] Moscow Domestic Service, 1200 GMT, March 20, 1987.

[40] Moscow Television Service, 2150 GMT, May 29,1987.

[41] Ibid.

[42] Pravda, July 26, 1987, p. 6. Kristillizator was not included in the list of equipment transferred from Salyut 7 to Mir even though a Kristillizator device had been delivered shortly before the T-14/T-13 crew departed.

The *Kasyun* experiment studied the influence of microgravity on the crystallization of aluminum-nickel alloy.[45] *Afarmiya* was designed to obtain single crystals of gallium antimonide.

### *Yantar (Spray Coating)*

Although the Soviets had not at that time specifically mentioned the apparatus they were using, on May 22 TASS reported that the crew was performing experiments for applying metal coatings by electron beam vaporization. They sprayed a copper coating on a polymer film, and also worked with vaporization of a copper-silver alloy.[46] On June 26, the device was identified as the Yantar unit. Additional experiments were carried out with little detail on what was being done.

### *Svetoblok (Gel)*

Svetoblok was used on Mir in July 1986 and July 1987. In the latter case, the Soviets reported that the crew was performing experiments related to obtaining synthetic helium to be used on Earth for the electrophoretic cleaning of substances.[47] There was a Svetoblok-T experiment on Salyut 7; it is not clear if this is the same device or a new version.

### *Svetlana and Ruchyey (Electrophoresis)*

The Kvant module carried a *Svetlana* automated electrophoresis plant for biotechnology experiments.[48] The first mention of using this device was during the Syrian mission where it was said the crew was producing antibiotics for livestock feed using Svetlana.[49] No further details were available at the end of 1987.

During the Syrian mission, the crew performed experiments with a unit called *Ruchyey* (Brook) to purify interferon and an influenza vaccine. It was said that this new device was more efficient and permitted better purification than earlier versions.[50]

The Soviets had previously announced that the *EFU-Robot* device had been transferred to Mir from Salyut 7, but no mention of its use was made through the end of 1987.

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[43] Pravda, July 26, 1987, p. 6.
[44] TASS, 1635 GMT, July 27, 1987.
[45] Izvestiya, July 27, 1987, p. 1.
[46] Izvestiya, May 23, 1987, p. 1.
[47] TASS, 1142 GMT, July 10,1987.
[48] TASS, 0908 GMT, March 31, 1987.
[49] Izvestiya, July 27, 1987, p. 1.
[50] TASS, 1635 GMT, July 27, 1987.

### *Other*

The *Biostoykost* (biostability) experiment was conducted beginning in June 1987. It was developed to study the possibility of using various polymer compounds as structural materials for new space instruments and equipment.[51] In October 1987, mention was made of the *Biryza* installation for studying the dynamics of physical-chemical processes in zero gravity. The report said the cosmonauts were calibrating the thermostat and carried out a test called *Color* to study the mechanism and peculiarities of formation of the three-dimensional structures in the course of chemical oscillatory reactions. The processes were registered on color film.[52]

## MEDICAL/BIOLOGICAL

Few specific references were made to medical experiments during the Mir missions, possibly because they have become so routine that the press does not think they merit reporting. The only new device mentioned was a data recording system called *Gamma*.[53] The cardiograph used on Salyut 7 was transferred to Mir by the Soyuz T-5 crew.

### *Medical*

The crew continued exercises, and the deputy director of the Institute of Biomedical Program, Dr. Grigoriev, commented that Kizim and Solovyev continued the *Sprint* regimen (perhaps meaning *Sport*, the new regimen used on Salyut 7) and he did not envision any time in the near future where exercise time could be reduced significantly. (General Shatalov gave a candid interview in which he expressed doubts about the need for all the exercise, however—see Chapter 5). Grigoriev went on to comment that experience gained in a cosmonaut's first spaceflight improves their performance in future missions and gives them certain psychological advantages. It may be that their physiological systems, primarily the regulatory ones, retain a memory of the previous spaceflight making it easier to adapt.[54]

The crew conducted experiments on July 3 related to "mastering techniques for clinical blood analyses in zero gravity" for the first time.[55] When the Syrian cosmonaut was aboard, studies were made of the cardiovascular system, and further blood studies using a centrifuge on board the space station to analyze blood taken from the crew. They also did the *Kontrast* experiment, described as the "study of the frequency-contrast characteristics of the visual system of man."[56]

### *Plant Growth*

Little was said about plant growth experiments, although it was clear they continued on Mir. There was one 1986 reference to the Soyuz T-15 crew having performed plant experiments on Mir and taken them over to Salyut 7, but otherwise no indication of what they were doing. The crew was reported to be working on the *Fiton* and *Rost* experiments in June 1987 for studying the development of high order plants and of various biological specimens in weightlessness.[57] There was another reference to Fiton in July.[58]

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[51] Moskovskaya Pravda, June 27, 1987, p. 2.
[52] TASS, 1146 GMT, October 9, 1987.
[53] TASS, 1702 GMT, April 11, 1986.
[54] Meditsinskaya Gazeta, August 6, 1986, p. 3.
[55] TASS, 1308 GMT, July 3, 1987.
[56] Moscow Domestic Service, 1300 GMT, December 18, 1986; TASS, 1635 GMT, July 27, 1987.

After the Syrian crew left, the Soyuz TM-2/TM-3 crew performed plant growth experiments with three month old seedlings of cedar trees and chlorophytum.[59]

## REMOTE SENSING OF THE EARTH AND ITS OCEANS

Remote sensing observations continued to be an important part of the experiments performed on Mir despite the absence of the MKF-6M camera which had been the hallmark of the Salyut 6 and 7 stations. Early in 1987, Progress 28 spacecraft delivered a KATE-140 camera "which has already been used in orbit."[60] This was an intriguing statement since the Soviets had previously announced that they had brought the KATE-140 camera over from Salyut 7. The new statement suggested that the Soyuz T-15 crew had returned the instrument to Earth with them, and it had then been relaunched on Progress 28. No easy explanation for this is available, since if the camera had broken, it presumably could have been repaired on orbit.

Another camera on Mir is called *Sevor* (North) which can take pictures at an angle rather than looking directly below the station. The images "come out in sharper relief with a distinct border between light and shade." The images from Sevor were superimposed with images from the KATE-140 topographic camera of the same area.[61]

### *Al-Furat (Euphrates)*

The Euphrates observations were performed while the Syrian cosmonaut was aboard using KATE-140. The objective was to study artificial reservoirs and their drainage systems, water resources, and forests and farm land.[62] The crew observed the basin of the Euphrates River and the Syrian desert to study the Asad and Ba'th water reservoirs and Lake Qatin.

### *Geoeks-86 and Tele-Geo-87*

Near the end of their mission to Mir, the Soyuz T-15 crew did observations called *Geoeks-86* as part of same "Study of Geosystem Dynamics by Remote Methods" program mentioned on Salyut 7.[63] Observations were made of East Germany using Mir, Cosmos 1602, and airplanes. The data were to be used for monitoring the condition of forests and farmland.

In July 1987, the Soyuz TM-2/TM-3 crew conducted remote sensing observations of Poland under the program Tele-Geo-87, while airplanes also took measurements.[64]

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[57] TASS, 0928 GMT, June 2, 1987.
[58] Moscow Domestic Service, 0600 GMT, July 10, 1987.
[59] Trud, August 5, 1987, p. 1.
[60] Sotsialisticheskaya Industriya, March 7, 1987, p. 1.
[61] TASS, 1846 GMT, March 6, 1987.
[62] Moscow Domestic Service, 1300 GMT, December 18, 1986.
[63] Izvestiya, July 15, 1986, p. 1.
[64] TASS, 1302 GMT, July 17, 1987.

## ASTRONOMY: THE KVANT MODULE

The Kvant module that docked with Mir in April 1987 had already provided sufficient information by October of that year to serve as the basis for special sessions at the Soviet Institute of Space Research's international space future forum and at the International Astronautical Federation annual meeting in Brighton, England. Its configuration had already been discussed at the previous year's IAF meeting in Innsbruck. The openness of the Soviet program was highlighted in these exchanges. It is unusual for the Soviets to discuss scientific probes in detail prior to launch, and discussions of the results obtained with them often take years.

Kvant is composed of two astronomy facilities, one for x-ray astronomy, the other for ultraviolet observations. The x-ray instruments are collectively know as *Roentgen* and weigh 800 kg. Roentgen was built cooperatively between Western Europe and the Soviet Union. The Europeans paid the full cost of developing and manufacturing their experiments while the Soviets provided satellite integration and launched it as part of their space station program.

The four x-ray instruments are as follows.[65] ESTEC, the technical center for the European Space Agency, provided the *Sirene-2 Gas Scintillation Proportional Spectrometer* (an improved version of earlier models like the one provided by France for Salyut 7). It can study x-ray sources in the 2–100 kiloelectronvolt (keV) range. Weighing 50 kg, it has a 2x2 degree field of view and an area of 314 square centimeters. The Sirene-2 studies clusters of galaxies which contain hot rarefied intergalactic gas. The State University of Utrecht in the Netherlands and Britain's Birmingham University provided a *Shadow Mask Imaging Telescope* (also called TTM). With a mass of 103 kg, a 10x10 degree field of view, and a 256x256 mm coding mask, it can image x-ray sources in the 2–30 keV range with high angular resolution. It is designed to make detailed studies of galactic centers, and observe black holes and neutron stars. The energy range from 1.7 keV to 9.4 keV is divided into 20 channels, 0.38 keV each; the energy range from 9.4 keV tk 14.2 keV is divided into five channels, 0.96 keV each; and the energy range from 14.2 keV to 25.7 keV is divided into six channels, 1.92 keV each. West Germany's Max Planck Institute provided a *Phoswich scintillation spectrometer* operating in the x-ray range from 15–200 keV. With a mass of 175 kg, four detectors and a 1.9x1.9 degree field of view, it studies x-ray spectra and their time variations. The Soviet Institute of Space Research provided the *Pulsar X-1* instrument for studying x-ray and gamma ray sources ranging from 20–800 keV. It has four detectors, a mass of 337.5 kg, and a 3x3 degree field of view. It is designed to search for bursts and pulsating x-ray sources, and look at the spectra of galactic nuclei and quasars.

The ultraviolet observatory is called Glazar (for "Galaxy" and "Quasar"[66]) and is also international: it was developed by scientists from the Byurakan Astrophysical Observatory and the Geneva Observatory in Switzerland. It performs all sky surveys to discover areas of excess ultraviolet emissions that might disclose the location of galaxies and quasars. Glazar's main mirror is 40 centimeters in diameter and has an electronic amplifier so that images of objects a million times fainter than those that can be observed with the unaided eye can be obtained. The photographs are recorded on film for return to Earth. Pointing accuracy of the Glazar instrument is two seconds of arc. The cosmonauts orient the space station complex generally in the direction the telescope needs to point; Glazar's own systems complete the orientation that it needs. After that, the crew needs only to change the film cassettes.[67] It is expected that it will take several years to carry out the entire program envisioned for the Glazar instrument.[68]

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[65] Sagdayev, R. et al. Complex X-Ray Observatory. Presented at the 1986 conference of the International Astronautical Federation in Innsbruck, Austria, October 1986; New Mir Astrophysics Module to Include European Experiments. Aviation Week & Space Technology, February 16,1987, p. 21.

[66] TASS, 1427 GMT, July 9, 1987.

Although Kvant finally docked with the space complex on April 12, the first experiments with it were not conducted until June 9, after the crew and Flight Control had developed experience in operating the gyroscopic orientation system. The first object of study by the x-ray telescopes was the supernova in the Large Magellanic Cloud discovered earlier in the year at the Cerro-Tololo Observatory in Chile. On August 10, 1987, Kvant detected unusually hard x-ray emissions from the supernova in the Great Magellanic Cloud. By that time, over 300 observation sessions had been conducted with Kvant.[69] Other objects of study included Centaurus, Cygnus, an x-ray pulsar in Hercules, and the Crab Nebula.

Glazar was first used on July 1, 1987.[70] It studied the Stern constellation in mid-July; the Grus, Pavo, Andromeda and Piscis Austrinis constellations in August, as well as the supernova.

### ATMOSPHERIC STUDIES

Almost no mention was made of atmospheric studies. An instrument called Missiya was reported to have been developed by the Syrians to do an experiment called Bosra for studying the ionosphere during the Soviet/Syrian flight.[71] In October 1987, the first mention was made on this mission of the *EFO-1* instrument.[72] It is unclear whether it was brought over to Mir from Salyut 7 or if it was a new device. Although the French PSN equipment was brought to Mir from Salyut 7, no mention was made of the cosmonauts using it during 1986–87.

### POLARIZATION

During the Syrian mission, reference was made to the *Polyarizatsiya* (polarization) experiment to perfect methods and equipment "for heightening the effectiveness of scientific research from space, and for the purpose of solving a number of navigational problems."[73] No clarifying details were forthcoming.

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[67] TASS, 1427 GMT, July 9, 1987.

[68] Pravda, May 20, 1987, p. 8. A later article said it could detect objects "hundreds of thousands of times weaker" than could be seen unaided. (TASS, 1427 GMT, July 9, 1987)

[69] TASS, 1609 GMT, September 22, 1987.

[70] Moscow Domestic Service, 1800 GMT, July 1, 1987.

[71] Moscow Domestic Service, 1300 GMT, December 18, 1986.

[72] TASS, 1220 GMT, October 6, 1987.

[73] Pravda, July 29, 1987, p. 1.

## MILITARY EXPERIMENTS

The issue of whether the Soviets use their space stations for military activities is highly controversial. It is extremely difficult to distinguish between certain military and civilian space activities in the first place. A camera that makes repeated observations of the Earth's surface can support both—it simply provides data that either community can use to its best advantage. Materials processing experiments are designed to discover what materials can be produced better in the absence of gravity. The materials can be used in either the defense industry or for consumer goods. Attempts to categorize activities as military or civilian are often rooted in politics, and the military/civilian distinction is in the eye of the beholder. Just about anything can be counted as military if someone wants to portray a space program as having a military slant, and vice verse.

The Soviet position on whether Mir is used for military experiments was succinctly stated by Cosmonaut Leonid Kizim on April 7, 1986 during his Soyuz T-15 mission: "The program for our work on board the Mir scientific station does not contain any experiments for military purposes. As for the statements by U.S. officials, it seems to us that they are being made in order to justify their own plans for transferring the arms race to space."[74]

The "statements by U.S. officials" included those in the 1987 edition of "Soviet Military Power," an annual report issued by the U.S. Department of Defense (DOD). The report described the Mir modules as providing the Soviets "with greater flexibility in performing missions such as reconnaissance, targeting, and military related R&D" as well as astrophysics, biology and materials processing. The report further asserts that:

> Soviet literature reports that the military applications of remote sensing, oceanography, meteorology, and geodesy have been the focus of repeated cosmonaut investigations. Even subjects such as astronomical observations, also performed by cosmonauts, have military use. Such investigations, for example, can provide data useful for maintaining the orientation of certain equipment to an accuracy of a few arcseconds, a capability needed to aim directed-energy weapons.
>
> The ability to rendezvous and manually dock with uncooperative spacecraft, which Soviet cosmonauts demonstrated in 1985 and 1986, also has military applications. Cosmonauts use a laser rangefinder, a night vision device, and an optical sight while performing this operation. The Soviets state that this procedure will allow the rescue of cosmonauts stranded in orbit, but it could also be useful for repairing friendly satellites and for inspecting and disabling enemy satellites.
>
> Conducting materials-processing experiments is an important cosmonaut function that has both civilian and military applications. Soviet efforts in this field, however, have concentrated on the production of substances with military significant applications regarding the development of semiconductor devices, infrared and optical detectors, and electro-optical systems.
>
> Another crucial cosmonaut activity is Earth observation, which has implications for reconnaissance and targeting applications. The Soviets report that their cosmonauts have used visual observations, camera, radars, spectrometers, and multispectral electro-optical sensors in their observations from SALYUT space stations. These experiments suggest the Soviets are evaluating their ability to locate, identify, and track targets from outer space as the first step toward designing a space weapons platform for use against targets in space and on Earth. Such a platform may even-

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[74] Moscow Television SErvice, 1430 GMT, April 7, 1986.

tually be used for ASAT [antisatellite] and ballistic missile defense operations as well as for space station defense.[75]

The considerable amount of Soviet literature reviewed for this report (as well as for the previous editions) does not make any mention of military applications of these activities, however. DOD's assertion that "Soviet literature reports" on such military applications is surprising.

The DOD approach to analyzing the Soviet space program is controversial. It is arguable that the DOD interpretation is inconsistent unless the definitions of "military" activities are equally applied to U.S. space activities. If DOD argues that virtually everything the cosmonauts are doing is or can be related to military goals, they would logically have to count as U.S. "military" space activities not only the programs DOD conducts (for reconnaissance, communications, navigation, weather, geodesy, ASAT and ballistic missile defense), but also all the activities performed by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA, in the Department of Commerce). The Mercury, Gemini, Apollo, and Space Shuttle programs, the Skylab space station especially, the automated Landsat land remote sensing satellites, NOAA's weather satellites, the many series of astronomical satellites (such as the High Energy Astronomy Observatories, the Infrared Astronomy Satellite, and so forth) could equally be described in the terms DOD uses in the above extract. Their *primary* purpose, however, is typically considered civilian/scientific, with the results disseminated openly.

If the same standards are applied to the Soviet space station activities as have been historically applied to U.S. space activities, then Mir would be considered civilian, like Salyut 1, 4, 6 and 7 before it. This is not to suggest that there are no potential military applications of the Mir experiments, or that there are no specific military experiments being conducted on Mir which the Soviets do not publicize. Rather, these would not be considered the main focus of the space station experiments, and that the majority of work conducted on Mir appears to be in what would normally be counted as civilian applications in this country.

It is interesting to note that in the debate over the need for a U.S. space station (which NASA is now building in cooperation with Europe, Canada and Japan), DOD has consistently and emphatically stated that it has no need for the space station.[76] DOD officials have vigorously intervened in the negotiations between the United States and its international space station partners to insure that they can have access to the space station in the future if they find a use for it, but repeatedly assert that they can accomplish all of their mission objectives better with automated spacecraft.

Contrary to the position expressed in "Soviet Military Power," Charles Cook, Air Force Deputy Assistant Secretary for Space Plans and Policy has said that the Air Force is "still uncertain as to what military value" the Soviets derive from Mir. He does not believe Mir's existence is a "militarily compelling justification for U.S. military involvement in the development of a similar complex," but acknowledged that "maybe the Soviets have found something that we don't know about."[77]

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[75] U.S. Department of Defense. Soviet Military Power–1987. Washington, U.S. Govt. Print. Off., 1987. pp.56–68. These assertions were repeated in DOD's November 1987 booklet "The Soviet Space Challenge."

[76] Smith, M. Space Stations. U.S. Library of Congress, Congressional Research Service. Issue Brief 85209 (continuously updated)

There have been Western allegations that the Soviets conduct very specific military experiments on space stations. One that has been attributed to activities on Mir surfaced in a July 15, 1987 *Wall Street Journal* editorial. Referencing "still classified U.S. intelligence," the editorial charged that a Soviet ICBM was targeted and tracked by a laser onboard Mir.[78] The editorial said that the test illustrated the practicality of using space-based lasers as part of a ballistic missile defense system, and complained that the Reagan Administration was unwilling to publicize the test for fear it would upset plans for a Reagan-Gorbachev summit. Two days later, unnamed "intelligence sources" were cited in *Defense Daily* as denying the Journal story. The newsletter stated: "reports of a Soviet test of a laser targeting and tracking system from the Mir space station, using a Soviet ICBM as a target, did not take place. The denial directly contradicted the report that the Administration is withholding disclosure of the event for fear of its effect on the development of plans for a summit."[79] A subsequent item in the newsletter quoted U.S. Soviet space analyst Nicholas Johnson as saying that there is no physical evidence the Soviets are conducting space-based weapons experiments.[80]

## 1986 ACTIVITIES

### SOYUZ T–15: A TWO-SPACE STATION MISSION

The first crew sent to Mir was Soyuz T–15, composed of two of the three crew members who had set the 237 day endurance record in 1984, Kizim and Solovyev. Launched on March 13, 1986, they not only activated Mir, but also became the first crew to "taxi" between space stations, transferring to Salyut 7 to complete activities left undone by the Soyuz T–13/T–14 crew and then transferring back to Mir. Total mission duration was 125 days, of which 51 were first spent on Mir, then 50 on Salyut 7, and then 19 more on Mir. It was the only mission to Mir in 1986. Activities on Salyut 7 are detailed in Chapter 2. There was speculation in the West that Mir and Salyut 7 would dock with each other to create a larger space station, but such rumors weakened after the announcement that the Soyuz T–15 crew would taxi over to Salyut 7, and were put to rest on April 8 when General Shatalov specifically stated that they had no plans to dock the two space stations.[81]

### *Initiating Operations With Mir*

Mir's orbital parameters after an orbital correction on February 24, 1986 were 352 x 324 kilometers, 51.6 degrees, 91.6 minutes. On March 4, the Soviet media reported that Mir's power, computer and docking systems had been tested successfully.[82] On March 7, Moscow World Service reported that the main and backup crews were completing their training for the first mission to Mir, but no specific launch date was announced.[83]

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[77] Defense Daily, May 11, 1987, p. 58.

[78] The "Mir" Experiment. Wall Street Journal, July 15, 1987, editorial page.

[79] Intelligence Says Mir Laser Test Did Not Take Place. Defense Daily, July 17, 1987, pp. 90–91.

[80] Soviet Space-Based Defense—No Physical Evidence. Defense Daily, July 17, 1987, p. 91.

[81] Trud, April 8, 1986, p. 4.

Five days later, TASS stated that preparations for launch were being completed and announced not only the names of the crew members, but the date and launch time as well: March 13 at 15:33 Moscow Time.[84] The Soviets have rarely announced launch dates in advance, much less specific times, unless they are associated with launches of foreign cosmonauts, so the announcement was viewed as a sign of the slowly increasing openness of the Soviet piloted space program.

The crew for this first mission to Mir was composed of two of the three men who had set the 237 day duration record on Salyut 7 in 1984: Col. Leonid Kizim and Vladimir Solovyev. As is typical, the call sign, Mayak, was retained (commanders keep the same call sign throughout their various space missions). The choice of Kizim and Solovyev was influenced by the early termination of the Soyuz T-13/T-14 mission. Cosmonaut Aleksey Leonov, deputy director of the Cosmonaut Training Center, noted that "Revisions in the training of crews were necessitated, of course, by the previous expedition's return ahead of schedule. . . . And in these conditions, specialists were unanimously of the opinion that the experienced, hard-working and friendly Kizim and Solovyev were the best prepared for the present flight." [85]

### *Launch and Docking*

Launch occurred as previously announced on March 13, 1986 at 15:33 MT and it was announced that docking would take place on March 15.[86] Live television coverage was provided.[87] The two day rendezvous time was unexpected, although the crew had alluded to the fact that one of their main training duties was practicing manual docking from a distance,[88] suggesting that this would not be a typical docking.

Docking occurred over the Atlantic near the equator at 16:38 MT on March 15, 12 minutes ahead of schedule.[89] The automated systems took over at a distance of 20 kilometers; the crew assumed manual control at 200 meters and then docked at the forward port.[90] The manual docking with the forward port was necessitated because Soyuz T-15 was not equipped with the new Kurs docking system incorporated on Mir, and was likened to Dzhanibekov's docking with Salyut 7 in 1985.[91] The Soviets at first explained that the new docking profile was intended to conserve fuel and was particularly important on this flight, but then immediately commented that it had required additional consumption of fuel.[92]

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[82] Izvestiya, March 4, 1986, p. 12.

[83] Moscow World Service, 0800 GMT, March 7, 1986.

[84] TASS, 1543 GMT, March 12, 1986.

[85] Pravda, March 15, 1986, p. 6.

[86] TASS, 1256 GMT, March 13, 1986.

[87] Moscow Television Service, 1215 GMT, March 13, 1986.

[88] Moscow Television Service, 1800 GMT, March 12, 1986.

[89] Trud, March 16, 1986, p. 1.

[90] In a March 16, 1986 Trud article, Cosmonaut Feoktistov said Soyuz T-15 approached Mir to within tens of meters and then "hovered" while ground controllers rotated the space station and Soyuz T-15 then flew around Mir to dock at the forward port. The part about rotating the station seems odd, since if they flew around the space station after ground control rotated the station in order to dock at the forward port, their initial rendezvous must also have been with the forward port. The reason for such a complicated ballet is unclear.

[91] Ibid.

The need for efficient use of Soyuz T-15's fuel quickly became evident. On March 15, Cosmonaut Dzhanibekov responded to a question about the future of Salyut 7 by saying that "It is still quite capable of working, and evidently in the very near future we will do some work there, too." When asked if the crew would "commute" between Mir and Salyut 7, Dzhanibekov replied "Indeed, it is expected that when some initial work . . . has been completed on the Mir station, that the . . . crew will fly across to the Salyut 7 station." [93]

Deputy flight director V. Blagov commented on the demands the space operations were putting on Flight Control Center personnel, saying that the controllers had to be divided into four groups: one for Mir, one for Soyuz T-15, one for Salyut, and one to prepare for the launch of cargo ships.[94]

At the time of the docking, it was announced that this was the last of the Soyuz T series spacecraft, and that it would be replaced with a new version (Soyuz TM) with a special docking systems for use with Mir.[95] After docking, the orbital parameters of the complex were 354 x 332 km, 91.2 minutes, 51.6 degrees.

### *Operations*

Cosmonaut Valeriy Kubasov noted that the space station would serve as a base for long term operations "with rotating crews." [96] This statement, coupled with similar Soviet comments over several years, led Western observers to believe that Mir would, in fact, be permanently occupied. This was not to be the case in 1986, however. Not only did the T-15 crew leave Mir to visit Salyut 7, but they returned to Earth in July 1986, leaving Mir unoccupied until February 1987. In April, 1986, General Shatalov noted that there would be a break between the Soyuz T-15 crew and the next one to visit Mir, saying that the station was not yet ready for permanent occupancy.[97]

As soon as the crew was aboard, a Progress cargo craft was launched (March 19, 13:08 MT). In fact, the crew had been admonished by Cosmonaut and Flight Director Valeriy Ryumin to conserve their food until the Progress spacecraft arrived since Mir was stocked with enough food for only 20 days.[98] Progress 25 docked with the aft port of the space station on March 21 at 14:16 MT. It was immediately clear that Progress spacecraft would serve the same functions for Mir as they had for Salyut, and on March 25 fuel was pumped into Mir's tanks from Progress 25. On March 28, TASS reported that the crew had finished unloading Progress 25,[99] and were testing the station's orientation systems. The next day they tested the new communications system for relaying communications to Flight Control through the Luch transponder on Cosmos 1700, and problems were encountered. Aerospace Daily reported that Western observers noted that one of the cosmonauts had counted forward and backward and asked if he could be heard, but his transmissions were not received by the ground.[100] The crew itself alluded to the difficulties in a press interview on April 27 when they were asked whether they were satisfied with Mir. One of the cosmonauts said that, as expected, some problems had developed. "For example, we had a big problem with the communication system. We could not adjust it for a long time." [101]

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[92] Ibid.

[93] Moscow Domestic Service, 1600 GMT, March 15, 1986.

[94] Pravda, March 15, 1986, p. 6.

[95] Moscow Domestic Service, 1339 GMT, March 15, 1986.

[96] TASS, 1842 GMT, March 15, 1986.

[97] Quoted in: Mir Not Yet Ready for Permanent Habitation. Defense Daily, April 15, 1986, p. 251.

[98] Izvestiya, March 21, 1986, p. 3.

[99] TASS, 1616 GMT, March 28, 1986.

On March 26, Mir's orbit was raised to 358 x 338 kilometers, 91.43 minutes from its previous orbit of 339 x 332 km, 91.18 minutes. Western observers noted that Salyut 7's orbit at that time was 345 x 340 km, 91.32 minutes, and that the orbital change meant that the two space stations were now drawing closer together. Speculation abounded that the "commute" to Salyut 7 would begin shortly.[102] Additional refueling was done on March 30 and April 1. On April 4, TASS announced that the crew was performing visual remote sensing observations, but that their work aboard Mir was coming to a close.[103] Despite these signs, the trip to Salyut 7 did not begin until the end of the month.

The crew held a televised press conference on April 7 from Mir using the Luch relay system. Foreign correspondents were allowed into the Flight Control Center for the press conference, an action viewed by the Western press as a further opening of the Soviet space program.[104]

On April 10, the crew had a series of medical checkups using the new medical data recording system Gamma. For the next several days, they conducted more visual remote sensing observations. Some Western observers have speculated that scientific modules were lagging behind schedule and the crew actually had little more to do on Mir than look out the window, since none of the scientific equipment had arrived. Soviet commentator Petr Pelekov said "I'll say bluntly that the [crew's] work hasn't produced a rich harvest of data; but space equipment, no matter how much you check it on earth, can only be tested in flight." [105] Press reports frequently referred to the fact that the crew's task was to activate the Mir station so that in the future it could serve as a base for scientific modules. The crew also conducted resonance experiments in which the crew runs and jumps while instruments measure the structural reaction of the space station complex. These tests were performed repeatedly on the Salyut space stations to test the structural integrity of the complex.

On April 19, Moscow Domestic Service gave another report that the crew had finished unloading Progress 25, making no reference to the March 28 TASS report that the cargo craft was unloaded,[106] again suggesting little activity on the crew's part. Progress 25 undocked at 23:24 MT on April 20 and immediately reentered.

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[100] Cosmonauts Begin Experiments Aboard Mir. Aerospace Daily, April 1, 1986, pp. 2-3.

[101] Moscow Domestic Service, 1730 GMT, April 27, 1986.

[102] Soviets Raise Orbit of Mir Space Station. Aerospace Daily, March 28, 1986, p. 483.

[103] TASS, 1032 GMT, April 4, 1986.

[104] Bohlen, C. Soviets Open Space Center to Foreign Press. Washington Post, April 8, 1986, p. A15.

[105] Moscow Domestic Service, 1930 GMT, April 23, 1986.

Progress 26 was launched three days later on April 23 at 23:40 MT and docked with the space station on April 27 at 01:26 MT. Geoffrey Perry of the Kettering Group noted that this was a 73 hour rather than a 48–50 hour rendezvous; the reasons were not clear, but he noted that the cargo craft overtook Mir and then came back to it.[107] Whatever the reasons for the unusual rendezvous, the crew had little time to work with Progress 26, since just eight days later they were to leave Mir and Progress 26 would be gone by the time they returned. No mention was made of unloading Progress 26, so it is not clear what it carried, other than fuel that was pumped into the station's tanks while the crew was gone. It is possible that the girder experiment later used on Salyut 7 was transported into space on Progress 26, since it was stated that the crew took 500 kg of material over to Salyut 7 with them.

After Progress 26 arrived, mention was made of the crew conducting remote sensing observations with hand held cameras, which may have been brought to the station by Progress 26, or it may be that the press simply had not noted the use of the cameras previously. The crew was also tending to plants during this time.

### *Visit to Salyut 7*

On April 30, V. Blagov announced that Mir was in "ideal working order, that all the technical 'weeds' had been pulled out, and that the station was 'tuned and playing like a grand piano' " and the crew would now transfer over to Salyut 7.[108] This process was described in the preceding chapter.

The crew left Mir on May 5 and returned on June 26. While they were gone, operations with Progress 26 were completed and it was undocked from Mir at 22:25 MT on June 23, reentering the same day. Fuel was transferred into the Mir tanks while the crew was gone and the Progress 26 engines were use to correct to complex's orbit on June 20. Also during this unoccupied portion of Mir's flight, the automated test of the new Soyuz TM was flown (see "Soyuz TM" section).

### *Back to Mir and Finally Home*

The crew returned to Mir on June 26 at 23:46 MT and remained for 19 days. With the equipment they brought over from Salyut 7, they were able to perform some experiments during this short time as described in the "Experiments" section. Among the devices brought to Mir from Salyut 7 were EFU-Robot, PSN, Niva, the KATE-140 camera, and Pion-M. *Pravda* noted that this equipment would be used "until scientific modules are sent up to the Mir station." [109] Remote sensing photography quickly became the priority objective, although experiments using the Svetoblok device were also carried out. It is not clear whether the Svetoblok unit was the one that had been used on Salyut 7, or if this was a new version delivered by Progress 26.

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[106] Moscow Domestic Service, 2230 GMT, April 19, 1986.

[107] Observers Note Extended Rendezvous With Mir for Progress 26. Aerospace Daily, April 30, 1986, pp. 171–2.

[108] Izvestiya, May 4, 1986, p. 3.

[109] Pravda, June 28, 1986, p. 6.

On July 3, Kizim, who had already accumulated 250 days on previous space missions, surpassed colleague Valeriy Ryumin (Soyuz 25, Soyuz 32/34, Soyuz 35/37) as having spent the longest cumulative time in space (362 days). Three days later he became the first person to have cumulatively spent a year in space.

On July 14, TASS reported that the crew was completing its work on Mir and preparing to return to Earth.[110] On July 15, TASS announced that the crew would return the next day. The crew undocked from Mir on July 16, and landed at 16:34 MT, setting down 55 km northeast of Arkalyk. Mission duration was 125 days and 1 minute.

A press conference was held with the crew on August 1, where it was noted that they had returned to their families two days earlier, or less than two weeks after landing. The press conference focussed on the entire mission, not just their time on Mir, and provided little new information.

### SOYUZ TM: AUTOMATED TEST OF A NEW VERSION OF SOYUZ

For Mir, the Soviets introduced another new version of the Soyuz spacecraft, this one designated Soyuz TM (for Soyuz Transport-Modified).[111] As has been true with previous design changes to spacecraft intended for use with crews, the Soviets tested it first in an automated mode. Its launch had been expected since the beginning of the Soyuz T-15 mission when it was announced that T-15 was the last of its series and would soon be replaced be a new model.

Soyuz TM was launched on May 21, 1986 at 12:22 MT. Its initial orbit was 240 x 200 km, 88.6 minutes, 51.6 degrees. Soyuz TM docked at Mir's forward port at 14:12 MT on May 23 (Progress 26 was at the aft port). Soyuz TM undocked from Mir on May 29 at 13:23 MT after only a brief stay in orbit. It landed the next day, but no specific time was given by the Soviets.

The new vehicle weighs 7,070 kg, is 6.98 meters long, has a diameter of 2.72 meters, a solar panel span of 10.6 meters, and a reentry mass of 3,000 kg. It can carry more into orbit, and return more to Earth. On May 23, 1986, Cosmonaut Valeriy Ryumin discussed the major differences between Soyuz TM and Soyuz T,[112] and other details have since become available, particularly in an August 5, 1987 Pravda article.[113] Unless otherwise noted, all the information in this section is from those two sources.

#### *Docking System Changes*

The most significant change is new approach and docking systems which allow the spacecraft to dock with Mir without requiring Mir to maneuver, thus saving fuel on the space station; the station's orientation no longer matters. The spacecraft approaches the space station and, depending upon which docking port it is assigned to, flies around the station to that port.[114] The new system is called Kurs (Course), replacing the old Igla (Needle) system. The Soyuz TM radar makes contact with station at 200 km; lock on begins when the ship is 20–30 km from the station.[115]

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[110] TASS, 1213 GMT, July 14, 1986.
[111] Moscow Domestic Service, 1600 GMT, February 6, 1987.
[112] TASS, 1744 GMT, May 23, 1986.
[113] Pravda, August 5, 1987, p. 3.

### *Parachute and Landing Systems*

Soyuz TM can carry 250 kg more payload into orbit and return 50- 60 kg more than the Soyuz T because of a new parachute system that uses lighter and stronger materials,[116] and it uses a slightly improved version of the standard launch vehicle. The parachute shroud lines are made of a new synthetic fiber.

At the time of the Soyuz TM–2 landing in July 1987, the Soviets reported that it had systems for more accurate landings. According to V. Pouchkayev, head of the Flight Control Center's ballistics unit, the braking engine operates for precisely 208 seconds, reducing the ship's speed by 115.2 meters per second, and "Even if an error of 5 meters per second occurs, the reentry vehicle will land within a few hundred kilometers of the specified point." He added that a special system had been developed for "placing a vehicle into the specified landing area if an error of this magnitude occurs," but it would increase the g-load on the crew from 3 to 11.[117] The spacecraft has an improved altimeter for firing the landing engines.

### *Other Onboard Systems*

The spacecraft has modernized power supply units. It has an improved orientation system, and uses improved onboard computers that allow procedures to be executed manually or automatically. The level of diagnosis that can be done by the onboard computers has been heightened. Main electrical systems are triple redundant.

### *Other Changes*

Other changes include a new communications system (for relaying communications through Luch, just like Mir itself). Monitoring by the Kettering Group has shown that the pulse duration modulated short wave transmissions on 20.008 MHz is no longer used.[118] The spacecraft also has a life support system with sufficient reserves that descent could be accomplished if the oxygen supply system failed. Soyuz TM has a more reliable engine that uses a metallic membrane to separate propellants from the gas used to pressurize the tanks. Elastic membranes had been used in the past, and after a time, gases could leak through and degrade engine performance. The interior has been improved: the design of the seat has been unified and areas are set aside for stowing gear.

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[114] Moscow Television Service, 1030 GMT, May 23, 1986.

[115] Izvestiya, February 9, 1987, p. 1.

[116] The 250 kg figure is from the Pravda article. Ryumin had said it could carry an extra 200 kg.

[117] Sovetskaya Rossiya, July 31, 1987, p. 1.

[118] Personal communication.

## 1987 Activities

### SOYUZ TM–2 AND TM–3: 326-DAY DURATION RECORD, AN UNPLANNED CREW REPLACEMENT, AND THE FIRST SYRIAN COSMONAUT

In 1987, the Soviet space program's flexibility was again tested when medical problems arose causing a change in crew plans. The two men launched in February on Soyuz TM–2 were to have set a new long duration record, but in the spring, one of the two (Laveikin) experienced heart irregularities. The Soviets had a visiting mission already scheduled to join the TM–2 crew in July, so they took advantage of the opportunity to replace Laveikin with another cosmonaut. Not only did this show the operational versatility of the Soviet program, but provided an opportunity to study the psychological aspects of making an unplanned replacement in the middle of the mission. Meanwhile, the other TM–2 cosmonaut, Romanenko, went on to set a new duration record of 326 days.

#### *Soyuz TM–2 Launch and Docking With Mir*

In December 1986, Mir's orbital parameters were reported to be 349 x 321 km, 91.1 minutes, 51.6 degrees.[119] In preparation for a new crew, Progress 27 was launched on January 16, 1987 at 09:06 MT and it docked at 10:27 MT on January 18. One unusual aspect of this Progress launch was the announcement that it carried medicines for the crew. No details were given as to what kind of medicines were delivered.

On January 28, the Soviets announced the names of the crew members who would travel to Mir: veteran cosmonaut Col. Yuriy Romanenko, and rookie Aleksandr Ivanovich Laveikin.[120] The launch of Romanenko and Laveikin on Soyuz TM–2 was carried live on television; the time of launch had been announced earlier in the day.[121] Launch time was 00:28 MT on February 6 (21:38 GMT, February 5). The crew used the call sign Tamir.

As with Soyuz T–15 and Soyuz TM–1, two days were used for the rendezvous. Docking was accomplished on February 8, 02:28 MT (February 7, 23:28 GMT) while the spacecraft were over China.[122] At the time of launch, the Soviets announced that the launch of a scientific module would not take place immediately because only one of the computers on Mir was functioning and that the software had to be updated.[123]

The crew entered the station and began reactivating it. Their workday was from 8 am to 11 pm Moscow Time.[124] From the beginning, it was speculated that the crew would remain in space for as long as 10 months, setting a new endurance record.[125] On February 9, the orbital parameters of the complex were 369 x 328 km, 91.4 minutes. On February 11, the Progress 27 engines were used for an orbital correction. The crew began unloading Progress 27 and performing medical and biological experiments. Moscow World Service reported that Laveikin had a rather "painful" adaptation to weightlessness.[126]

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[119] Vechernyaya Moskva, December 20, 1986, p. 1.

[120] Moscow Domestic Service, 1100 GMT, January 28, 1987. An interesting anecdote was published in Pravda about Romanenko about this time. It recalled the Soyuz 26 mission in 1977 when Romanenko was paired with Georgiy Grechko on Salyut 6. Grechko was inspecting the outside of the space station by standing in the EVA hatch while Romanenko held him from inside the station. Romanenko asked to take a look outside the hatch and as Grechko moved aside, Romanenko "shot up into the hatch opening. Grechko looked and saw that the safety line on Romanenko's suit had not been fastened to anything, and he grabbed it just in time." (Pravda, February 6, 1987, p. 3.)

[121] TASS, 1022 GMT, February 5, 1987.

[122] Cosmonauts in Second Day Aboard Mir Space Station. Aerospace Daily, February 10, 1987, p. 211. In the article, Geoffrey Perry notes that dockings normally take place over the Crimea in better view of radar and other facilities at Tyuratam, but on this occasion both spacecraft were still in the Earth's shadow at that time.

[123] Pravda, February 6, 1987, p. 3.

[124] Sotsialisticheskaya Industriya, February 10, 1987, p. 1.

On February 23, Progress 27 undocked from Mir at 14:29 MT; it reentered on February 25. The crew began remote sensing observations and experiments using the Pion-M instrument, and commented on February 28 that they were awaiting the arrival of the astrophysics module "impatiently." [127] They noted that not only would it bring the x-ray astronomy facilities, but also "interesting experimental life- sustaining equipment which will enable us to . . . obtain oxygen directly during the flight." [128] The crew also talked about a tulip they were growing on the space station and a control tulip being grown at mission control.

Progress 28 was launched on March 3, 1987. It docked with Mir on March 5 at 15:43 MT. On March 10, the complex's parameters were 386 x 355 km, 91.7 minutes, following a correction using the Progress engines. It undocked from Mir on March 26 at 08:08 MT and reentered on March 28.

The next crew activity was the arrival of the Kvant astrophysics module. As detailed below, this was a prolonged exercise because of unexpected docking problems. Despite the original setback on April 5, the Soviets went ahead with a scheduled press conference on April 6 with the Syrian cosmonauts who were in training for a July mission to Mir. Information regarding the Kvant situation is described below. The orbiting crew participated in the press conference for only 10 minutes because of Mir's orbit, suggesting that the Luch relay system for communications was not working. During the conference, Romanenko responded to a question about how long his mission would be by saying that "we shall make no secret of the fact that our flight is to be a lengthy one." [129] It was also revealed that the Soviets continue to follow the practice of requiring the crew to don spacesuits and retreat to the relative safety of the Soyuz module during dockings. While it is well known that this safety measure had been followed earlier in the space station program, it is somewhat surprising that they have not discontinued this time-consuming practice based on their considerable experience. During the Kvant docking operations, however, it was clearly stated that the crew had moved into the TM-2 and that "these precautionary measures are always taken before a docking." [130]

### *Kvant Astrophysics Module*

The Kvant (Quantum) astrophysics module was the first scientific module sent to Mir. Great difficulties were experienced in docking the module with the space station and a crew EVA was required to diagnose and correct the problem.

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[125] Cosmonauts Launched. Aviation Week and Space Technology, February 9, 1987, p. 27.
[126] Moscow World Service, 0900 GMT, February 14, 1987.
[127] Moscow Television Service, 0015 GMT, February 28, 1987.
[128] Ibid.
[129] Moscow Television Service, 1847 GMT, April 7, 1987.
[130] Leningradskaya Pravda, April 10, 1987, p. 3.

The first hint that an astrophysical module would be the first to dock with Mir came in December 1986 when Valeriy Ryumin was discussing plans for the upcoming year. On December 18, 1986 he said that an astrophysical module would be docked with the space station prior to the visit by the Syrian cosmonaut.[131] This was reiterated on January 4, when it was stated that the module would be launched "shortly." [132] In February, the Soviets stated again that an astrophysics module would be the first to dock with Mir and went on to describe how scientific modules would dock first with the forward port and then swing around to the side port,[133] leaving the impression that Kvant would in fact dock at a side port. This was not to be the case, however.

### *Docking Difficulties Require EVA*

Kvant was launched on March 31, 1987. Weighing 20.6 tonnes at launch, it was approximately the same size as the Mir space station. It consisted of both the observatory (11 tonnes, 5.8 meters long with a diameter of 4.15 meters, habitable volume 40 cubic meters) and a service/propulsion module which was jettisoned after docking with Mir.[134] It went into an initial orbit of 320 x 177 km, 89.2 minutes, 51.6 degrees, and the Soviets announced that it would dock with Mir on April 5.[135] On the day of launch the Soviets announced that Kvant would dock with the aft port, not one of the side ports.

After an orbital correction on April 2, Kvant's orbital parameters were 346 x 297 km, 90.9 minutes. At 14:30 GMT on April 5, Moscow Television Service announced that a problem had developed with the Kvant docking. The report stated that Romanenko and Laveikin had seen Kvant out the window and "the rendezvous was taking place under controlled final approach conditions. The flight was proceeding normally. When the Kvant and Mir were separated by 200 meters—during the final section—the rendezvous was suspended because of faults in the control system of Kvant." [136]

This bland statement did not truly do justice to the situation. Not only did Kvant carry a treasure trove of scientific equipment, the gyroscopes for orienting the station, a new type of life support system for replenishing oxygen, and new solar panels to be added to the station, all of which would be lost if docking could not be achieved, but the event itself surely would have startled any cosmonaut. According to the Kettering Group, the two spacecraft passed each at a distance of only 10 meters! [137]

The Soviets continued to "assess" Kvant's condition, hedging their comments as to whether they would attempt another docking.

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[131] Moscow Television Service, 2043 GMT, December 18, 1986.

[132] Izvestiya, January 4, 1987, p.3.

[133] TASS, 1234 GMT, February 7, 1987.

[134] TASS, 0908 GMT, March 31, 1987.

[135] TASS, 0626 GMT, March 31, 1987.

[136] Moscow Television Service, 1430 GMT, April 5, 1987.

[137] Reported in Kidger, N. Mir Mission: Third Solar Array Installed. Spaceflight, August 1987, p. 282.

At an already-scheduled press conference the day after the docking failure, Valeriy Ryumin said that they would decide "in a few days," while Alexandr Dunayev, head of the Glavkosmos organization, said that the docking had been aborted "because of the low probability situation which occurred had not been provided for in the control program of the module." [138] Dunayev stated that the problem had been with the approach systems on Kvant.

> An irregular situation occurred in the space orbit on Sunday night. During the rendezvousing of the spacecraft, which was proceeding strictly according to the calculated flight path, the system "Igla" installed on the Kvant module suddenly "lost" the orbiting station when the module was approximately 200 meters from it. . . . We understand clearly enough what happened in orbit. Requirements for the mutual positioning of the spacecraft in the in-close phase of their flight paths were set much too rigid. The technical name for such a situation is "logic of tolerances." What we had fed into the computer, we obtained as a result." [139]

He added that specialists were determining when another attempt to dock could be made and that the date would not be kept secret. In the interim, the two spacecraft drifted 400 km apart.[140]

Another docking attempt was made on April 9 and a soft-docking was achieved at 04:36 MT. This jinxed module still caused the Soviets problems, however, for a hard-docking could not be accomplished. The TASS announcement disclosed the problem:

> The process of securing the module tightly to the station began after the docking mechanisms of the spacecraft had been mechanically connected. Analysis of telemetry information received from the spacecraft indicated that tight securing of the Kvant module to the orbiting station Mir had not been fully accomplished.
>
> Data are now being studied, and a decision in regard to further work with the module will be made on the basis of results of the study.[141]

Understandably distressed, the Soviet press stated that the spacecraft were only centimeters apart. The crew surveyed the situation through the windows and with cameras on the outside of the station, but could not detect the problem. Finally, the decision was made to have the crew perform an EVA so they could inspect the situation first hand. During the night of April 11-12 (Cosmonautics Day—the celebration of Gagarin's flight), the crew left Mir to rescue the Kvant module. They exited the station at 23:41 MT on April 11. They physically separated Kvant from Mir and found that docking "was being prevented by an extraneous object which had come between them." They removed it, and ground controllers docked the two craft.[142] The cosmonauts said that it looked like a small white bag, but it has not been further identified by the Soviets, probably because they also do not know exactly what it was. On April 25, the Soviet press reported that specialists at the Flight Control Center were still debating what it might have been. "The cosmonauts were unable to identify the mysterious object in the white wrapping. After it was cut, it floated off into space." [143] Western reports speculated that it might have been a protective covering, label or bag mistakenly left on Kvant by the ground crew,[144] but the Soviets "unequivocally rejected" this possibility based on photographs of Kvant taken at the launch site prior to launch.[145]

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[138] Soviets to Decide In "A Few Days" On New Kvant Docking Try. Aerospace Daily, April 7, 1987, p. 34.

[139] Komsomolskaya Pravda, April 8, 1987, p. 4.

[140] Ibid.

[141] TASS, 0849 GMT, April 9, 1987.

[142] TASS, 0215 GMT, April 12, 1987.

[143] Komsomolskaya Pravda, April 25, 1987, p. 1.

The crew's EVA lasted 3 hours and 40 minutes, in what a Soviet commentator aptly called a "heroic" mission.

### *Configuration*

Kvant carried one and a half tons of scientific instruments and two and a half tons of equipment, including additional solar panels which the crew installed during an EVA in June, a water electrolysis unit for supplying oxygen, and gyroscopes for orienting the complex. The scientific equipment included the Roentgen x-ray observatory and the Glazar gamma-ray instrument.

The habitable portion of Kvant is divided into a working compartment and a transfer compartment; there also is an unpressurized scientific payload bay that "girdles" the outside of the transfer compartment for instruments and systems that must be exposed to space.[146] It has two windows, one with a diameter of 43 centimeters for setting up an optical sight and another 22.8 centimeters in diameter for a visual star tracker. Two eight centimeter portholes in the transfer compartment are for visual observations. There is also an air-lock for servicing the ultraviolet telescope.[147]

As already noted, another major aspect of Kvant is that it houses the gyroscopes used for orienting the space station complex. The weight of a gyroscope and its supporting units is approximately 165 kilograms, they have an expected lifetime of 3–5 years, and consume about 90 watts of electricity.[148] Details of Kvant's scientific payload and experiments with it are described in the "Experiments" section.

### *Back to Work*

With Kvant finally secured, the crew was able to settle down to work activating Mir and its many instruments. On April 13, the service propulsion unit of Mir was detached at 00:18 MT, and it was announced that Kvant had two docking units: one for docking with Mir, and another on the opposite side to enable continued dockings of Progress and Soyuz spacecraft without having to detach Kvant.[149] Thus, it became clear that Kvant was to be docked with Mir for a long time.

On April 21 at 19:14 MT, just eight days after the Kvant propulsion unit was detached and the docking port cleared, the Soviets launched Progress 29 which docked with the Kvant aft port on April 23 at 21:05 MT. With the addition of Progress 29, the Soviets had created a truly modular space station: Soyuz TM–2, Mir, Kvant, and Progress 29 all docked together laterally. With the announcement that Progress 29 carried fuel for Mir's engines, it also clarified the fact that refueling lines are included in the Kvant design. The refueling lines are located at the Mir aft port, and with Kvant in between the Progress cargo craft and Mir, the lines would have to extend through Kvant. In what was hardly an understatement, TASS announced: "In this way a sophisticated research complex of four spacecraft integrated into a single whole had been built through successive dockings for the first time in the world." [150]

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[144] EVA Performed to Dock Kvant Module to Mir. Aviation Week and Space Technology, April 20, 1987, p. 21. Western sources have variously said it was made of plastic or cloth.

[145] Ibid.

[146] TASS, 0908 GMT, March 31, 1987.

[147] Sovetskaya Latviya, April 1, 1987, p. 3.

[148] Lenorovitz, J. Soviets Use New Gyros to Stabilize Mir Station. Aviation Week and Space Technology, November 2, 1987, p. 79.

[149] TASS, 1002 GMT, April 13, 1987. At last report, the Kvant service module was still in orbit. A report in Flight International said that it could not reenter because, after the docking difficulties, it had insufficient fuel for a controlled reentry (October 24, 1987, p. 36.)

The same day, the crew started powering up the gyroscopes. One month was allowed for "mastering the control of the gyroscopes, and this is considered to be a record short time. In time these clever spinning tops will control the station's orientation by means of electronic signals from Earth, but for the time being the help of the station's crew is needed. Every day, the crew will check the rotation by means of a solar sextant." [151] While the Soviets said at first that this was the first time they had used gyroscopes in their piloted space program, later they stated that they had experimented with them on Salyut 3 and 5.[152] Progress 29 undocked from Mir at 07:10 MT on May 11 and reentered the same day. Progress 30 quickly followed. It was launched on May 19, and docked at 09:53 Moscow Time on May 21.

### *EVA To Add Solar Panel*

Another important task the crew had to perform was the addition of the third solar panel to Mir. As noted, the space station was launched with two arrays, larger than the Salyut arrays and generating 10 kw of electricity. Nevertheless, the large amount of scientific equipment and the gyroscopes on Mir/Kvant required additional power. Kvant delivered the new solar panels and the Soviets announced that the crew would attach them during an EVA in early May.

The competing demands and heavy workload on the crew quickly evidenced themselves, however. Although they needed the additional electricity, the crew also had many other tasks to perform. Too many—the EVA was postponed. TASS reported on May 6 that: "Owing to the large volume of different kinds of work that the crew has had to perform, the mission program has been revised, and work in open space which had been scheduled for the beginning of May has been postponed to a later time." [153]

On May 28, the Soviets made clear that they still needed to get the new solar panels working. Moscow World Service stated that the Mir complex "had begun to experience a shortage of electricity." The statement noted that Kvant was consuming electricity and that in addition the crew was welding semiconductors in the Korund unit "which consumed a lot of power." [154]

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[150] TASS, 1920 GMT, April 23, 1987.
[151] Komsomolskaya Pravda, April 25, 1987, p. 1.
[152] Pravda, September 6, 1987, p. 3.
[153] Izvestiya, May 7, 1987, p. 2.
[154] Moscow World SErvice, 0700 GMT, May 28, 1987.

On May 29, TASS reported that the crew had installed another storage battery "in the base block and connected it to the electrical system." [155] This was the first step in the procedure.

Next, the crew had to actually install the solar panels. For this, they completed two EVAs on June 12 and June 16. Although crews had added solar panels previously, this was a different matter. In the earlier cases, they had attached solar panels to the existing main arrays which were already wired into the space station. This time, they were creating an entirely new array and installing the supporting elements to attach them to the space station and connect with the internal circuitry.

The first EVA began at 20:55 MT on June 12 and lasted 1 hour 53 minutes while the crew brought the bulky equipment out to the exterior of the space station. On June 16, they performed a 3 hour 15 minute EVA beginning at 19:30 MT. After hooking up the electric connections for all the solar array's sections, they unfolded it to its full length of 10.6 meters in an exercise reminiscent of the girder- extending activity carried out by the Soyuz T-15 crew in 1986. Total effective area of the new array is 22 square meters, and it added 2.4 kw of electricity.[156] Also on this EVA, the crew attached cassettes of materials to the outside of the station as had been done in many previous EVAs.

On June 23, the crew completed hooking up the solar arrays to the station's circuitry from inside the complex.

### *Time for a Few Experiments*

With the electricity situation under control, the crew turned their attention to experiments and maintenance. They initiated use of the Kvant astrophysical instruments. At the end of June they replaced one of the Strela units with an improved version to expand the capabilities for controlling onboard systems and instruments.[157]

On July 19, just three days before the long-awaited launch of the crew including a Syrian cosmonaut, Progress 30 undocked from the complex at 04:20 MT. It reentered the same day.

### *Soyuz TM-3 Visits With a Syrian Cosmonaut; Unplanned Crew Replacement*

In December 1986, the Soviets announced both the launch date and time for the space mission that would carry a Syrian cosmonaut: July 22 at 06:30 MT. Joint experiments were identified, including remote sensing under the program Al-Furat (Euphrates) using the KATE-140 cameras. They also announced the prime and backup crews, rather unusual so early in advance. The prime crew was Lt. Col. Aleksandr Stepanovich Viktorenko, pilot; Aleksandr Pavlovich Aleksandrov, flight engineer; and Lt. Col. Muhammad Ahmad Faris, research cosmonaut. (The backup crew was Lt. Col. Anatoliy Solovyev, Viktor Savinykh, and Lt. Col. Munir Habib.) [158]

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[155] Pravda, May 30, 1987, p. 1.

[156] Gudok, June 16, 1987, p. 4.

[157] Moskovskaya Pravda, June 27, 1987, p. 2.

[158] Moscow Domestic Service, 1300 GMT, December 18,1986; Moscow Television Service, 2043 GMT, December 18, 1986.

Throughout the first half of 1987, while the Soyuz TM–2 crew was aboard Mir, the impending Soviet/Syrian mission was publicized, with several press conferences including the Syrian cosmonauts. Finally, on July 22 at 05:50 MT, 40 minutes earlier than had been announced in December, the Soyuz TM–3 mission was launched. A Syrian delegation was present at Tyuratam to witness the launch, headed by General Mustafa Talas, Syrian deputy prime minister, deputy commander in chief of the Army and the Armed Forces, and minister of defense.

The three-man crew docked with Mir on July 24 at 07:31 MT. This was the first docking of a Soyuz to the Kvant port. The crew transferred into Mir and it appeared that this would be a routine visiting mission, with the three men returning after a week onboard Mir. Later that day, however, there was a surprise announcement: Laveikin, 35, would be returning to Earth with Viktorenko and Faris, while Aleksandrov would remain onboard. The problem—anomalous readings from Laveikin's cardiograms had worried doctors on the ground and they had decided to bring him home. It is not clear when the problem developed, but deputy flight director Blagov said that it had been a "planned" replacement,[159] indicating that they had made the decision to replace Laveikin prior to the Soyuz TM–3 launch. The need to change Aleksandrov's plans from a seven day mission to one lasting several months apparently did not concern them.[160]

Further reports from the Soviets about Laveikin's problem were not specific. They stated only that his cardiograms had registered abnormalities while under physical exertion, and that although he had not evidenced any health problems, they decided to return him because of difficulties in forecasting their further development.

The scientific program for the Syrian mission included photography of Syria, atmospheric studies, materials science studies, and medical studies. After the usual seven days on board the space complex, the crew returned to Earth on July 30 in the Soyuz TM–2 spacecraft landing at 05:05 MT 140 km northeast of Arkalyk. Viktorenko and Faris had been in space for 7 days, 23 hours and 5 minutes; Laveikin's duration was 174 days, 3 hours and 26 minutes (the same duration as the TM–2 spacecraft).

At the post flight press conference the next day, medical specialists announced that Laveikin was fine and that "no trouble of the cardiovascular system or other organs had been diagnosed." They said that the abnormalities they saw were "within the particular qualities of his organism," and added that preventative measures had been taken during the flight "which, apparently, ensured the necessary effect." [161]

Laveikin's psychological attitude after his return was more questionable; he seemed at best irritated at the course of events. Pravda reported that when the crew arrived back at Baikonur, all three walked down the airplane's ramp,[162] but in the evening, Laveikin announced that he would go to dinner by himself and that nothing had to be brought to him as if he were ill. The reporter commented that "Frankly, we journalists were a little surprised that a collective meeting, so to speak, was permitted only with A. Viktorenko and Mohammed Faris. We were told that we would meet Laveikin later, in his room." When they arrived, Laveikin was standing, and joked that he did not understand why he was receiving such close attention from the physicians. Indeed, the article then quoted medical specialists as saying that "If it were not for the cardiograms from orbit, one would feel absolutely that the cosmonaut had simply returned from his prolonged flight with no problems whatsoever." [163]

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[159] Tass, 100 GMT, July 24, 1987.

[160] Aleksandrov had been on Salyut 7 for 149 days in 1983 where he also had to adjust to changing circumstances when the original Soyuz T–10 crew could not join the T–9 crew in orbit because of a launch failure.

[161] TASS, 1413 GMT, July 31, 1987.

Whatever the problem, doctors were satisfied that he was fine now that he was back on Earth. The head of the clinical department of the National Cardiological Center, Nurmukhamed Mukharlyamov, said on August 5 that after he had completely readapted to Earth's gravity (in about two months), he would be put through another thorough checkup. "It is only then that the cause of the change in the heart rhythm in orbit can be determined." [164] In November 1987, Mukharlyamov said that Laveikin was "practically healthy. After he went through the traditional package of readaptation routines, a supplementary examination has detected nothing wrong with the cosmonaut's health. Laveikin is feeling fit for further space launches." [165]

### *The New Crew Settles Down to Work*

The new pair of Romanenko, ending his fifth month onboard the space station, and Aleksandrov, still adjusting to space conditions, started back to work. The first task, of course, was changing the position of the Soyuz TM-3 spacecraft which was still at the aft Kvant docking port. On July 31, the crew entered Soyuz TM-3 and undocked from Mir at 03:28 MT. Mir was rotated 180 degrees by ground control, and redocking occurred at 03:48 MT.[166]

Next came another cargo craft. Progress 31 was launched on August 4 at 00:44 MT (August 3, 2044 GMT). Docking was achieved on August 6 at 02:28 MT (August 5, 22:28 GMT). They resumed operations with the Roentgen x-ray telescopes on Kvant. Plant growth experiments were resumed, including three month old seedlings from cedar trees and chlorophytum brought by the visiting crew.

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[162] A television report said, however, the Laveikin did not deplane with the others, but left the plane and boarded a bus unaided. A video picture later showed all three cosmonauts standing by the plane. (Moscow Television Service, 1430 GMT, July 30, 1987)

[163] Pravda, August 1, 1987, p. 2.

[164] TASS, 1618 GMT, August 5, 1987. It should be noted that cosmonauts (and astronauts) are loathe to admit medical problems in orbit. A revealing anecdote was published in October 1987 about Romanenko when he first flew in space on Soyuz 26. Told by Georgiy Grechko, his partner on the mission, the story explained that near the end of the mission Romanenko developed a toothache, but said nothing about it. Grechko noticed that he was taking painkillers several times a day, "considerably exceeding the dose. I did not want to bother him with questions, as I thought he would tell me himself. But he kept quiet about it, and I could see that his eyes were literally rolling with pain." Grechko suggested he contact the doctors on the ground, but Romanenko refused because "it would be a disgrace to complain of a toothache." Grechko was concerned about Romanenko's ability to do his job, particularly at that time (just before the visit of the first international cosmonaut), but "Yuriy stubbornly insisted on having his own way. We eventually agreed that I would tell earth that I was the one with a toothache and Yuriy would follow

[165] TASS, 0731 GMT, November 18, 1987.

[166] TASS, 0711 GMT, July 31, 1987.

On August 21, Moscow World Service announced that the Romanenko/Aleksandrov mission would continue "until the end of the year." [167]

At the end of August, the crew conducted an emergency evacuation rehearsal. They put on their spacesuits and entered the Soyuz TM-3 capsule and prepared to return to Earth. The Soviet media called it an "unusual experiment" to "help the cosmonauts to act quickly and be ready to take safety measures in the event of an unforeseen situation." [168]

Throughout September, the crew conducted remote sensing and astrophysical observations. Progress 31 undocked from Mir on September 22 at 03:58 MT and reentered the same day. Progress 32 was launched on September 24 at 03:44 MT (September 23, 2344 GMT). The spacecraft docked with the space complex at 05:08 MT on September 26.

### *Breaking the Endurance Records*

The next benchmark accomplishment for the mission came on October 1 when Romanenko equalled the record for space endurance of 237 days. Previously, of course, it had been all three members of the Soyuz T-10/T-11 crew who set the record, but this time it was Romanenko alone who achieved this distinction since Aleksandrov was a relative newcomer to the space station.

It was not surprising that early in October Romanenko complained of fatigue. The Soviet press noted that specialists had determined that the optimum space mission duration was 3-4 months, and if measured by that yardstick, Romanenko had served a double tour of duty. Romanenko was quoted as saying:

> Fatigue makes itself felt, of course. For example, I never used to notice noise from the fans at all, but now it sometimes wakes me up at night. Sometimes I don't fall asleep right away in the evening, or I wake up in the middle of the night, and then I'm not myself in the morning. People on the ground already know about these difficulties I'm having, and Sasha Aleksandrov treats me considerately if I oversleep, they try not to wake me. If I get more tired than usual during the day, I take medicine at night, according to advice from medical personnel.[169]

As Romanenko was passing the old endurance record (according to international rules, a new record must exceed the old one by 10 percent, so Romanenko did not set a new record until later), the Soviet Union was celebrating the 30th anniversary of the launch of Sputnik 1 by holding an international space future forum at the Institute of Space Research in Moscow. One of the sessions at the forum was devoted to results from the supernova studies conducted with Kvant, and the participants in the forum were able to talk with the crew in orbit.[170]

Meanwhile, the crew continued a full range of experiments. On October 6 they were reported to be experimenting with the synthesis of polyachrylamide gel in the Svetoblok unit and performing atmospheric studies with the EFO-1 instrument. On October 16 they participated in a "telebridge" with French scientists.[171]

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[167] Moscow World Service, 1100 GMT, August 21, 1987.

[168] Moscow World Service, 0700 GMT, August 31, 1987.

[169] Izvestiya, October 2, 1987, p. 6.

[170] Izvestiya, October 6, 1987, p. 3.

Western press reports said that the crew's work day had been reduced to 5.5 hours, quoting the Soviets as saying that the "crew feels a certain tiredness" and "every new flight is a step into the unknown—therefore medics act with caution." [172]

Romanenko began setting a new duration record on October 24 when he passed his 261st day in space. By this time, he was also catching up with the record held by Leonid Kizim for the greatest total cumulative amount of time in space (375 days). Romanenko, who had accumulated 104 days on his previous flights, broke that record on November 3, 1987.

On November 10, the crew conducted a fuel consumption test with Progress 32. The cargo craft undocked from the complex at 07:09 MT. At a distance of 2.5 kilometers, the two craft began approaching each other again and redocked at 08:47 MT. The TASS announcement said that the test was related to upgrading methods of holding dynamic operations on orbit. "New algorithms for controlling the movement of spacecraft, designed with the aim of cutting the consumption of fuel" during docking exercises were tested.[173] Progress 32 finally undocked from Mir on November 17 at 22:25 MT and reentered on November 19.

During this time, Mukharlyamov reported that both crew members were in good health, and the psychological atmosphere aboard the station was good.[174] He noted that the most important aspects of keeping the crew healthy was regular exercise, a reasonable combination of work and leisure, and a balanced diet to help keep vital elements such as potassium and calcium.

Progress 33 was launched at 02:47 MT on November 21 and docked at 04:39 MT on November 23. It was the seventh cargo craft for this mission. On December 2, Romanenko passed the 300 day mark of his mission, and the Soviets announced that he would return to Earth on the eve of the new year. They also reported that Romanenko was "visibly tired" and his leg muscles had shrunk 15 percent, but his cardiovascular system was normal.[175] The crew's work day was reduced to 4-4.5 hours.

### SOYUZ TM-4: A NEW CREW TAKES OVER

A few days later, on December 9, the Soviets presented a new crew (and their backups) to journalists.[176] The commander of the new crew, Col. Vladimir Georgiyevich Titov, would be trying to board a space station for the third time: his first try, in April 1983, failed when the Soyuz T-8 docking radar did not deploy so docking could not be achieved with Salyut 7; his second attempt was on September 23, 1983—the mission that was aborted when the launch vehicle caught fire seconds before launch (Soyuz T-10A). Titov's crewmates this time would be Musa Khiromonovich Manarov [177] and Anatoliy Semenovich Levchenko. Press announcements stressed that Levchenko was a meritorious test pilot. The launch date and time were announced three days in advance,[178] and two days before launch it was reported that Levchenko would return with Romanenko and Aleksandrov while Titov and Manarov took over operations on Mir.[179] Progress 33's departure from the space station on December 19 (undocking occurred at 11:16 MT) cleared the rear docking port for Soyuz TM-4's arrival. The cargo craft reentered the same day.

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[171] Moscow Domestic Service, 1200 GMT, October 17, 1987.

[172] Covault, C. Soviet Biological Satellite Misses Target by 2,000 Miles. Aviation Week and Space Technology, October 19, 1987, p. 33; Cosmonauts "Tired," Work Day Cut to 5.5 Hours, Aerospace Daily, October 19, 1987, p. 95.

[173] TASS, 1034 GMT, November 10, 1987.

[174] TASS, 0731 GMT, November 18, 1987.

[175] TASS, 0854 GMT, December 3, 1987.

[176] TASS, 1832 GMT, December 9, 1987.

Soyuz TM-4 (call sign Okean) was launched at 14:18 MT on December 21; docking was achieved on December 23 at 15:51 MT. Although the Soviets had transferred operations from one crew to another on Salyut 7, this time it was a complete crew rotation; no one already familiar with the operation would be left on board as Savinykh had been in 1985. This placed greater demands on Romanenko and Aleksandrov during the one week they shared with the new crew on the space station, both in terms of acquainting Titov and Manarov with the station and its experiments, and in packing their own things to go home. Coupled with experiments that they crew was still expected to perform during this period, the work load was too much. Tired and irritable, Romanenko lambasted ground controllers the day before he returned to Earth, complaining that he and Aleksandrov were "rushing around like squirrels in a wheel" trying to do everything that was demanded of them. He insisted that "superfluous personnel" (presumably scientific specialists worried about their experimental results) be removed from the control center, and suggested that experiments should not have been planned during the period of joint work with the new crew.[180]

### *Romanenko Returns with Aleksandrov, Levchenko and a 326 Day Record*

On December 29, after 326 continuous days in space, Romanenko finally came home. Soyuz TM-3 undocked from Mir at 08:55 MT and Romanenko, Aleksandrov, and Levchenko landed at 12:16 MT. Romanenko's new continuous record of 326 days was coupled with a new cumulative record of 431 days. His precise duration on this flight was 326 days 11 hours and 38 minutes; Aleksandrov was in space for 160 days 7 hours and 17 minutes. Levchenko's duration was 7 days 21 hours and 58 minutes.

It was a rough end to the record-breaking mission. At the landing site, 80 kilometers from Arkalyk, visibility was 4 kilometers, the temperature was minus 12 degrees C and weatherman warned of the possibility of icing that could prevent search planes and helicopters from taking off (in which case cross-country vehicles would have to be used to retrieve the crew).[181] Moscow television showed film of the landing.[182] The picture showed the capsule descending until it was lost in fog, and then showed it lying on its side on the ground. Correspondent Slipchenko explained that strong wind gusts (25–30 meters/second) had blown it over, and that plans to erect a medical tent near the capsule before removing the crew had to be scuttled, so the crew was taken directly to a medical helicopter.

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[177] Manarov's first name appears variously in the Soviet press as Musakhiy, Musat and Musa.

[178] Moscow Domestic Service, 0700 GMT, December 18, 1987.

[179] TASS, 1352 GMT, December 19,1987. The report also listed Aleksandr Shchukin as Levchenko's backup.

[180] Izvestiya, December 30, 1987, p. 1,3.

[181] Moscow Domestic Service, December 29, 1987, 0639 GMT.

Television shots showed Romanenko and Aleksandrov being carried from the capsule, while Levchenko, supported by a man on either side, got into a helicopter and viewers were told that he was being taken to an airport to "fly to Moscow to continue his work. He will be piloting a plane after his period of weightlessness." [183] The television report then shifted to an airplane carrying Aleksandrov and Romanenko, and the correspondent reported that the two had changed clothing, "stood up and sat down at the table and are now eating our earth food with great pleasure." (Laveikin was also aboard the plane.) Romanenko was half lying down in his chair and was later shown deplaning at Baikonur with people supporting him on either side. Their arrival at Baikonur showed another interesting change in the Soviet space program: they were met at the plane by their families. Slipchenko ended his report on this note, saying that "For the first time in very likely the whole history of manned space exploration, a crew at Baikonur is welcomed by their families, wives and children. They will be seeing in the New Year all together." [184]

From Soviet press accounts, the two men were in better shape than might have been expected. A Soviet television reporter, looking for Romanenko the day after the landing, found him walking in a park with his wife and a physician.[185] A Western commentary said that his wife had her arm linked with his, but that Romanenko appeared to walking very confidently.[186] At a press conference that day, the cosmonauts attributed their good health to the measures they had followed on orbit. Aleksandrov revealed that he and Romanenko had been able to choose their own exercise regimens to some extent. He stated that Romanenko had "adopted the program he believed he needed" and that he had "scrupulously worked on this program. It was simply astonishing how conscientiously and single-mindedly, and with what willpower, he did this, because getting on the running track and running the 4 k we are obliged to run every day remains the most difficult thing for us in flight." For himself, Aleksandrov chose a less intense program.[187] At the same press conference, Romanenko said that his mission was the latest step in sending people to Mars.

### *Levchenko's Mission: Paving the Way for the Space Shuttle*

Mostly missed by Western press accounts of the mission, Levchenko's presence on the flight was quite interesting. The day before the launch, Gen. Shatalov explained to Soviet journalists that Levchenko's mission was needed to gain experience related to piloting a reusable space system.[188] As Soyuz TM-4 docked with Mir, the Soviet press announced that: [He] has been sent on this mission to try out in zero gravity his skills for the future piloting of a shuttle spacecraft being developed in the Soviet Union." [189]

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[182] Moscow Television Service, 1800 GMT, December 29, 1987.

[183] Ibid.

[184] Ibid.

[185] Moscow Television Service, 1530 GMT, December 30, 1987.

[186] Ibid. Commentary by FBIS inserted in story.

[187] Moscow Domestic Service, 1835 GMT, December 30, 1987.

As noted above, after landing, Levchenko was taken to an airfield where he flew an airplane (a TU-154). Although Soviet television said that he was going to fly to Moscow to continue his work, he participated in a press conference with Romanenko and Aleksandrov at Baikonur the next day. (He may have flown to Moscow and back.) Apparently the Soviets were testing how his piloting abilities were affected by a week in weightlessness. They reported that he had passed the test "with flying colors." [190] (The Soviet press also commented that Levchenko was "the most laconic participant in the news conference" and answered questions with just two or three words, and Romanenko and Aleksandrov had to come to his assistance.)

### *Beginning the Era of Permanent Occupancy?*

As 1987 ended, Titov and Manarov were settling in aboard Mir. The Soyuz TM-4 spacecraft was moved to the forward port using the standard procedure on December 30, freeing the rear port for resupply flights. Moscow World Service announced that the crew would remain in orbit for a year, and quoted deputy flight director Blagov as saying that it was a "small step to a manned flight to Mars." [191]

During 1988, plans call for Titov and Manarov to be visited by two crews carrying foreign cosmonauts. First will be a Bulgarian, Aleksandur Aleksandrov (not to be confused with the Russian Aleksandrov who just returned to Earth), scheduled to be launched on June 21 with Vladimir Solovyev and Viktor Savinykh.[192] The Bulgarian Aleksandrov served as his countryman Georgiy Ivanov's backup on Soyuz 33; that spacecraft was unable to dock with Salyut 6 in 1979 because of an engine failure. In November, a Frenchman (either Jean-Loup Chretien who flew on Soyuz T-6 in 1982 or Michel Tognini) is scheduled for launch. This joint mission will last a month, rather than a week.[193]

Blagov stated that it was "quite likely" that a doctor would fly to Mir to examine the cosmonauts, raising the possibility that one of the visiting crews will include a physician. Neither of the Soviet cosmonauts announced as members of the June mission are physicians. Whether the Soviets are leaving open the possibility of changing that crew, or plan to send the doctor along on the November mission, is unclear. It is also possible that there will be an all-Soviet crew that visits Titov and Manarov that would include a doctor. An interesting announcement was made in January 1988 that as part of one of the international visiting missions, the cosmonauts would perform a spacewalk using "jet bicycles." [194] This is probably connected with the French visit to Mir since it had been previously reported that the French cosmonaut would perform a spacewalk.

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[188] Moscow Television Service, 1530 GMT, December 20, 1987.

[189] Moscow Domestic Service, 1200 GMT, December 23, 1987.

[190] Moscow Domestic Service, 1835 GMT, December 30, 1987.

[191] Moscow World Service, 1500 GMT, December 24, 1987.

[192] Sofia BTA, 1850 GMT, December 25, 1987. The backup crew is Vladimir Lyakhov, Aleksandr Serebrov, and Bulgarian Krasimir Stoyanov.

[193] Paris AFP, 0904 GMT, October 21, 1987.

Barring unforeseen difficulties, the transfer of operations from Romanenko and Aleksandrov to Titov and Manarov should signal the beginning of permanent occupancy of Mir. Ten years after the launch of Salyut 6, which opened the possibility of a permanently occupied space station by virtue of its two docking ports, the Soviets may finally have achieved their goal.

The next module will not be launched to Mir until late 1988 or early 1989 according to Soviets speaking at the October 1987 meeting of the International Astronautical Federation.[195] It will be for remote sensing, and include a special airlock for EVA egress. Next will be the materials processing module, followed by a life sciences module called Medilab. The full space station will not be complete until the 1990s. This is somewhat slower than had been expected by Western analysts, and may reflect difficulties in preparing the modules themselves. Another factor is that the Soviets have said that their primary interest in a space shuttle is for returning material to Earth, which could be a reference either to the products developed in the module or the modules themselves.[196] Thus the development of the shuttle, and its launch vehicle Energiya, may also be pacing items in the full development of the space complex.

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[194] Moscow World Service, 1200 GMT, January 4, 1988.

[195] Personal observation at October 1987 IAF Congress, Brighton, England.

[196] Ibid.

## TABLE 9.—CREWS SENT TO MIR: 1986–87

| Mission | Launch date [1] | Reentry date [1] | Duration | Comment |
|---|---|---|---|---|
| Soyuz T–15 | 03/13/86 | 07/16/86 | 125 days | Spent 51 days on Mir, then "taxied" to Salyut 7 for 50 days, then returned to Mir for 19 more days. Activated the Mir space station; ended crew operations on Salyut 7. |
| Soyuz TM | 05/21/86 | 05/30/86 | 9 days | Automated test of new Soyuz variant. |
| Soyuz TM–2 | 02/05/87 | 07/30/87 | 174 days [2] | Romanenko and Laveikin were launched on Soyuz TM–2. Laveikin returned to Earth on July 30 in Soyuz TM–2 with two members of the crew launched on Soyuz TM–3. Romanenko stayed aboard with Aleksandrov, who had been launched on TM–3. Duration for Laveikin was 174 days. |
| Soyuz TM–3 | 07/22/87 | 12/29/87 | 160 days [2] | Included Syrian Cosmonaut M. Faris. Faris and Commander A. Viktorenko returned on Soyuz TM–2 on July 30. Duration was 8 days. Aleksandrov remained on Mir with Romanenko until Dec. 29. Duration for Romanenko was 326 days; for Aleksandrov, 160 days, which is also the ship duration. |
| Soyuz TM–4 | 12/21/87 | In orbit | | V. Titov and M. Manarov took over Mir operations and are on board as of Dec. 31, 1987. A. Levchenko was also launched on TM–4, but returned on TM–3 with Romanenko and Aleksandrov; his duration was 8 days. |

[1] Date reflect Greenwich Mean Time, not Moscow Time.

[2] Reflects ship duration. There is no "crew duration" since the crews did not stay together. See comments column for crew rotation aspects and duration of each individual—the longest duration was Romanenko's 326 days.

Prepared by Marcia S. Smith, CRS.

## TABLE 10.—CARGO AND MODULES FLIGHTS TO MIR: 1986–1987

| Mission | Launch date [1] | Reentry date [1] | Duration | Comment |
|---|---|---|---|---|
| Progress 25 | 03/19/86 | 04/21/86 | 33 days | 31 days docked. |
| Progress 26 | 04/23/86 | 06/23/86 | 30 days | 27 days docked. 3 day rendezvous instead of usual 2 days for unknown reasons. Undocked while no crew was aboard. |
| Progress 27 | 01/16/87 | 02/25/86 | 40 days | 36 days docked. Docked with Mir while no crew aboard. |
| Progress 28 | 03/03/87 | 03/28/87 | 25 days | 21 days docked. |
| Kvant | 03/31/87 | Still docked | | Astrophysics module docked docked at rear Mir port. Has two ports of its own, so it can remain permanently docked with Mir while Progress and Soyuz spacecraft dock with its second port. Docking problems overcome by crew intervention. |
| Progress 29 | 04/20/87 | 05/11/87 | 41 days | 39 days docked. Docked at Kvant port, as did the subsequent Progress missions. |
| Progress 30 | 05/19/87 | 07/19/87 | 56 days | 54 days docked. |
| Progress 31 | 08/03/87 | 09/22/87 | 50 days | 48 days docked. |
| Progress 32 | 09/23/87 | 11/19/87 | 56 days | 52 days docked. |
| Progress 33 | 11/21/87 | 12/19/87 | 28 days | 26 days docked. |

[1] Dates reflect Greenwich Mean Time, not Moscow Time.

Prepared by Marcia S. Smith, CRS.

## CHAPTER 4—SPACE LIFE SCIENCES

The Soviet Union was the first nation to launch a living organism (a dog, in 1957) into orbit, and the first to place a man in space (Yuri Gagarin, in 1961). A Soviet woman, Valentina Tereshkova, was the first female space traveler, and a Soviet cosmonaut was the first to engage in extravehicular activity (EVA) in space. Soviets were the first to inhabit a space station, and the first to accomplish many of the operations that will be crucial to future human exploration and development of space. Over the past three decades, the Soviets have steadily pursued the development of a strong and many-faceted program of space life sciences research in support of piloted space activities.

Their ultimate goal, in this carefully interlinked program of space medical and biological research, is to extend human occupation of space to the longest possible duration—ideally, to remove all biomedical limitations to spaceflight, whether in near-Earth orbit or interplanetary space. The near-term goal is to provide the biomedical support necessary to achieve permanent human presence in space through crew rotation. All Soviet space life sciences work is apparently directed at acquiring the knowledge and developing the procedures and technologies that will be needed to attain these goals. The same cautious, stepwise approach evident in the development of Soviet space vehicles also characterizes the life sciences program.

### HIGHLIGHTS: 1984–1987

This four-year period saw major steps being taken toward attainment of the near-term Soviet goal of achieving permanent human presence in space. Several important records and milestones in human habitation in space were attained. But that progress did not take place without incident; at least two significant problems of a biomedical nature occurred.

#### SALYUT 7 TO MIR: LARGE STEP TOWARD PERMANENT PRESENCE

A significant milestone on the way to permanent occupation of space stations was achieved in September 1985, when the crew of Soyuz T–14 relieved the Soyuz T–13 crew aboard Salyut 7. (Specifically, one of the T–13 crewmembers returned to Earth with one of the T–14 cosmonauts, leaving the second T–13 crewman behind with the two other T–14 cosmonauts.) This event marked the first time that successive crews have occupied a space station without interruption. The second crew might itself have been relieved by a third long-term crew in 1986, had not one of the T–14 cosmonauts become ill (see below).

The launch of the next-generation Soviet space station, Mir, in February 1986 opened a new phase in Soviet piloted space activities. As described in Chapter 3, Mir is not vastly different from its predecessor Salyuts, but some of its new features are highly significant from a biomedical standpoint. In particular, the four additional docking ports permit much more of the internal volume of the space station proper to be used as habitable space for the crew since the scientific equipment is now in the modules instead of underfoot, increasing the potential size of crews as well as their comfort. Other features such as the two private crew compartments and life support upgrades will also improve the habitability of the station—particularly for long-term missions, in which the environment has a great impact on crew performance and psychological health.

An important operational achievement having life sciences implications was the visit to Salyut 7 by the Soyuz T–15 crew in May 1986. This first transfer between operational space stations by any crew provided powerful evidence of the resourcefulness of humans in space, and of their effectiveness under unpredictable and difficult working conditions. Cosmonaut versatility was further displayed in April 1987, when the crew of Soyuz TM–2 aboard Mir made an unplanned EVA to assist in docking the Kvant astrophysics module to Mir.

As of the end of 1987, the Soviets have carried out 62 piloted space missions, including among their crews cosmonauts from 12 other nations. With the experience now gained, the series of Soviet piloted space stations may be nearing the end of its experimental stage, with permanently occupied modular complexes just over the horizon.[1] [2] Indeed, many believe that the Soviet goal of permanent human presence in space has now been achieved, and that the next major challenge to Soviet life sciences is long-duration piloted flight beyond Earth.[3]

### NEW HUMAN DURATION RECORDS

As of the beginning of 1984, the long-duration spaceflight record of 211 days (set by the Soyuz T–5/T–7 crew aboard Salyut 7) had stood for more than a year. On February 8, 1984, a three-man crew was launched to Salyut 7 on a mission designed to test long-term human adaptability to spaceflight. Leonid Kizim, Vladimir Solovyev, and Oleg Atkov remained in space for 237 days—just under 8 months, or approximately the time for a one-way trip to Mars.

TABLE 11.—PILOTED SOVIET SPACEFLIGHTS AND BIOSATELLITES: 1984–87

| Mission | Launch date | Duration (days) | Crew/organisms |
|---|---|---|---|
| Salyut 7: | | | |
| Soyuz T–10/T–11 | 02/08/84 | 237 | Kizim, Solovyev, Atkov. |
| Soyuz T–11/T–10 | 04/04/84 | 8 | Malyshev, Strekalov, Sharma. |
| Soyuz T–12 | 07/17/84 | 12 | Dzhanibekov, Savitskaya, Volk. |
| Soyuz T–13/T–14 | 06/06/85 | 112*/168** | Dzhanibekov*, Savinykh.** |
| Soyuz T–14/T–13 | 09/17/85 | 9*/65** | Grechko*, Volkov**, Vasyutin.** |

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[1] Johnson, N. L. The Soviet Year in Space: 1986. Teledyne Brown Engineering, Colorado Springs, Co, January 1987, p. 65.

[2] Pesavento, P. Sputnik's Heirs: What the Soviets Are Doing In Space. Technology Review, October 30, 1987, pp. 27-35.

[3] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

TABLE 11.—PILOTED SOVIET SPACEFLIGHTS AND BIOSATELLITES: 1984–87—Continued

| Mission | Launch date | Duration (days) | Crew/organisms |
|---|---|---|---|
| Mir: | | | |
| Soyuz T–15 | 03/13/86 | 125 | Kizim, Solovyev. |
| Soyuz TM–2/TM–3 | 02/06//87 | 326*/174** | Romanenko*, Laveikin**. |
| Soyuz TM–3/TM–2 | 07/22/87 | 160*/8** | Alexandrov*, Viktorenko**, Faris**. |
| Soyuz TM–4 | 12/21/87 | [1] */8** | V. Titov*, Manarov*, Levchenko**. |
| Biosatellites: | | | |
| Cosmos 1667 | 07/10/85 | 7 | 2 rhesus, 10 rats, newts, fish, insects, plants. |
| Cosmos 1887 | 09/29/87 | 14 | 2 rhesus, 12 rats, fish, insects. |

[1] V. Titov and Manarov were in orbit as of December 31, 1987.

Prepared by Courtland Lewis for CRS.

Late in 1987 that record was broken by cosmonaut Yuriy Romanenko, prime crew member on the Soyuz TM–2/TM–3 mission who set a new record of 326 days. (Romanenko's first partner, Alexander Laveikin, returned to Earth after 174 days due to the appearance of arrhythmias in his electrocardiogram, as described below. He was relieved by another cosmonaut.) In the course of setting a new piloted spaceflight duration record, Romanenko also broke the record for total time in space by an individual, with 431 days in his three missions. Romanenko is one of a number of cosmonauts who have now completed more than one long-duration flight. No biomedical problems due to repeated long-duration flight have been noted by the Soviets; nor, according to Soviet sources, has a single exposure to long-term flight produced significant medical problems as long as a suitable program of countermeasures was adhered to.[4] (The topics of long-duration spaceflight, adaptation to the space environment, and countermeasures to it are described in detail in the next major section.)

As of the end of 1987, Soviet cosmonauts have accumulated almost 14 person-years in space. This figure contrasts sharply with the U.S. total of 4 years and 10 months. The large experience gap is obviously a result of the U.S. emphasis in recent years on short-term flight in the Space Shuttle, in contrast with the consistent Soviet emphasis on long-term habitation of space stations. Nevertheless, the difference in space experience represents a substantial gap in data regarding the human response to spaceflight conditions, especially for longer, for the United States.

### VASYUTIN ILLNESS

The Soyuz T-14/T-13 mission to the revived Salyut 7 in 1985 ended early when mission commander Vladimir Vasyutin became ill. The 33- year-old rookie cosmonaut took command of the mission when Georgiy Grechko and Vladimir Dzhanibekov returned to Earth on September 25, 1985. Fellow cosmonaut Viktor Savinykh noted in his diary that, shortly after taking command, Vasyutin began to appear "tense, a bundle of nerves," and took to his sleeping bag with a fever.[5]

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[4] Gazenko, O. G., et al. Man in Space Flight (IAF/IAA-87-527). Presented at the 38th Congress of the International Astronautical Federation, Brighton, UK, October 10–17, 1987.

[5] Pravda, December 29, 1985, p. 3.

On November 13, the Kettering Group in England, began monitoring scrambled communications between Salyut 7 and Flight Control Center. As it turned out, the cosmonauts were discussing Vasyutin's condition with space medicine specialists. According to a Western source, Dr. Oleg Gazenko, director of the Institute of Biomedical Problems and the foremost figure in Soviet space life sciences, diagnosed Vasyutin's problem as an inflammatory disease and prescribed medication from the onboard medical kit.[6] However, the cosmonaut's condition did not improve and he apparently needed "very complex treatment," so a decision was made to terminate the mission. On November 21, 1985, the three-man crew boarded their Soyuz ferry craft and returned to Earth.

Vasyutin was taken immediately to a Moscow hospital, where he remained for a full month before being released to return to Star City. He was soon seen in public, and did appear to have recovered fully.[7] According to NASA space medicine specialists, Soviet sources later described his condition as a renal system inflammation.[8] Based partly on cryptic Soviet remarks about "a cold going into new forms" and "attacks of pain" other Western sources speculated that the problem could be kidney stones or appendicitis, a flu-like illness, or even viral pneumonia.[9] [10] Vasyutin had reportedly suffered from a high fever (as much as 104 degrees F) and inflammation for three weeks before the mission ended.[11] However, no data have been officially released by the Soviets on the exact nature of his condition or its treatment. One interesting supposition concerns the development of renal calculi (kidney stones). The increased excretion of calcium seen during the early phases of spaceflight might be expected to increase the likelihood that calculi will form, especially if calcium supplements are being taken; however, there is no evidence that renal calculi have ever developed, during or after flight, in any Soviet or American space crew member.

This incident apparently marked the first time in the history of the Soviet space program that a mission was curtailed due to illness of a cosmonaut. Vasyutin had spent 65 days in space. The two other cosmonauts, Savinykh and Alexandr Volkov, were described as weak but healthy.[12] (Savinykh had been in space for 168 days, Volkov for 65.)

## LAVEIKIN CARDIAC ANOMALIES

Alexandr Laveikin, of the two-man Soyuz TM-2/TM-3 long-duration crew aboard Mir, was returned to Earth on July 30, 1987 due to an apparent heart problem. Soviet physicians had detected "changes in Laveikin's electrocardiogram" over a period of several weeks, in telemetry monitored during physical stress tests and periods of heavy work aboard the station.[13] The condition was later described as "irregular heart rhythms" by Anatoliy Grigoriev, deputy director of the Institute of Biomedical Problems.[14] At the time Laveikin was removed, he was not ill and was performing a normal workload. He returned with two members of a visiting crew.

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[6] Harford, J. American Institute of Aeronautics and Astronautics. Trip Report of March 1986 Visit to Soviet Union, p. 9.

[7] Canby, T. A Generation after Sputnik: Are the Soviets Ahead in Space? National Geographic, October 1986, pp. 420-459.

[8] Nicogossian, A. E., NASA Life Sciences Division, personal communication, October 19, 1987.

[9] Soviet Union Ends Space Mission Because of Commander's Illness. New York Times, November 22, 1985, p. A4.

[10] O'Toole, T. Illness That Forced Cosmonaut's Return a Mystery to NASA. Washington Post, November 27, 1985, p. A3.

[11] Moscow Television Service, Moscow, 1530 GMT, December 20, 1985.

[12] Canby, T. Y. Are the Soviets Ahead in Space? op. cit.

After his return, Laveikin was described as healthy and without pain, as he underwent the normal postflight examination and rehabilitation program.[15] [16] A Soviet cardiologist said that the state of Laveikin's health "does not differ from the usual condition" of cosmonauts returning from long-term missions. Three-and-one-half months after his return to Earth, Soviet doctors announced that further tests had "detected nothing wrong with the cosmonaut's health."[17]

Laveikin had been aboard the Mir station for 174 days at the time of his return to Earth. Shortly after he had arrived on the station in February 1987, it was noted that he needed rest and had had a "painful" adaptation to zero gravity.[18] When the arrhythmias occurred, Soviet space physicians decided not to attempt to treat Laveikin with drugs because of the likelihood of unwanted side effects. Similar arrhythmias have been seen in the American space program: Two U.S. astronauts on the Apollo 15 lunar mission developed arrhythmias almost simultaneously while preparing to leave the lunar surface; another brief episode was seen in the last Skylab mission during bicycle ergometer exercise.[19]

Laveikin's partner, Yuriy Romanenko, remained aboard Mir with Alexandr Aleksandrov of the visiting crew, who replaced Laveikin. Romanenko later set a new space endurance record, as described above.

## TOPICS OF SPECIAL INTEREST

### COSMONAUT SELECTION AND TRAINING

In the space programs of both the United States and the Soviet Union, the selection and training of crew members is considered to be of primary importance. Given the emphasis that is placed on long-term occupation of space stations in the Soviet program, the role of humans—and their health and capabilities while in space—are increasingly crucial to the success of the program.[20]

### *Selection Process*

Early in the history of the Soviet space program, as in the U.S. program, cosmonauts were selected from among the ranks of experienced military pilots and (in a few Soviet cases) civilian pilots or parachutists.[21] As the technical complexity of space missions has increased, however, both programs have broadened their selection bases to include candidates with extensive technical and scientific backgrounds. This encompasses individuals with advanced degrees in engineering, geology, medicine, and physics. Although the Soviet program distinguishes cosmonaut-pilots from cosmonaut-scientists in terms of their training, as the U.S. program does with the Pilot and Mission or Payload Specialist categories, the distinction is not very strong in terms of selection in the Soviet program. With some minor exceptions, medical requirements are equally stringent for both categories; however, this may change in the future.[22]

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[13] Soviets Launch Massive Earth Survey Platform. Aviation Week and Space Technology. August 3, 1987, pp. 27–28.

[14] Soviets to Extend Duration of Manned Missions. Aviation Week and Space Technology. October 19, 1987, p. 116.

[15] Pravda, August 1, 1987, p. 2.

[16] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

[17] TASS, 0731 GMT, November 18, 1987.

[18] Moscow World Service, 0900 GMT, February 14, 1987.

[19] See, for example, Physiological and Psychological Parameters of Life in Space Stations (interview with Charles A. Berry, MD), Spaceflight, January 1981, pp. 23–26.

[20] Skibis, I. A., et al. Biomedical Preparation of Cosmonauts. In L. Hooke et al. (eds.), USSR Space Life Sciences Digest, NASA CR-3922(10), no. 9, 1987, p. 89.

Cosmonaut candidates range in age from 25 to 45 years, and include both men and women. (Cosmonaut-pilot candidates can be no older than 35.)[23] There is an extensive youth program of cosmonautic space clubs that brings teenage students into early contact with the space program and provides a point of entry into the cosmonaut candidate pool.[24] Selection of foreign cosmonauts is made on roughly the same demographic and medical basis, but relative fluency in the Russian language is reported to be an additional selection factor.[25]

### *Medical/Psychological Evaluation*

Rigorous medical and psychological evaluations are the primary criteria for cosmonaut selection. The evaluations are conducted in three stages. First, preliminary screening is performed on an outpatient basis by a team of medical specialists representing internal medicine, neurology, ophthalmology, ear-nose-throat, endocrinology, and other specialties. A medical history of each candidate is compiled. Based on the clinical and historical data, an evaluation board then recommends whether the candidate should continue to the next stage.[26] [27]

The second stage consists of extensive clinical evaluations intended to exclude hereditary disorders and recurring pathological conditions, particularly those affecting the circulatory, respiratory, urinary, gastrointestinal, and skeletal systems. Evaluative tests include roentgenography, endoscopy, electrocardiography, and electroencephalography. Extensive laboratory tests including hematological and blood chemistry evaluations are performed. Neurological, endocrinological, and ophthalmological examinations are carried out. An otolaryngological examination includes tests of vestibular function. This parameter receives considerable attention due to the prevalence of problems with "space motion sickness" in the early phase of space flight (see following section, "Adaptation to Space, Readaptation to Earth," for a more detailed discussion).[28]

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[21] Link, M. M., et al. Selection of Astronauts and Cosmonauts. In Foundations of Space Biology and Medicine, v. 3, 1975, p. 419–437.

[22] Vyadro, M. D., and I. I. Bryanov. Development of the Soviet System for Medical Selection of Cosmonauts (Hospital Stage). Kosmicheskaya Biol. i Aviak. Medit., 1986, pp. 3–7.

[23] Ibid.

[24] Bednyakova, O. The Cosmodrome in the Heart of Moscow. Soviet Life, April 1981, pp. 18–21.

[25] Remek, V. Communication Problems of International Crews. Presented at the 30th Congress of the International Astronautical Federation, Munich FRG, September 17–22, 1979.

[26] Link, M. M., et al. Selection of Astronauts and Cosmonauts, op. cit.

[27] U.S. Congress, Senate Committee on Commerce, Science, and Transportation. Soviet Space Programs: 1976–80—Manned Space Programs and Space Life Sciences (Pt. 2). Staff Report, 98th Cong., 2nd Sess. Washington, U.S. Govt. Print. Off. October 1984, p. 679.

A variety of functional examinations are carried out to test physiological systems under stressful load conditions. These include: the effects of moderate degrees of hypoxia on cardiovascular function; a "dive" test to evaluate the capacity of the ears and sinuses to adjust to changes in barometric pressure; and tests of cardiac function during exercise and changes in posture. Pulmonary, neurological, and vestibular stability are tested under stress loading, as is the ability of candidates to withstand centrifugal forces applied in both the "head-toe" and "chest-back" directions. An important aspect of these stress tests is the determination of a candidate's reserve capacity, or physiological "cushion," at different loads.[29]

The second stage of evaluation also includes a range of psychological tests. This parameter has taken on increasing significance as the length of missions has increased.[30] [31] The Soviets utilize the most up-to-date psychological evaluation techniques. Selected personality features are examined using projective and non-projective methods of personality testing.[32] Other psychological tests are done to measure perception, intellectual abilities, psychomotor efficiency, and physiological indices of emotional reactivity. Desired characteristics include: low anxiety level, well-balanced emotional makeup, extroversive personality, a high level of intellectual and perceptual capacity, high resistance to extended mental work, long attention span, good attention separability and changeability, good memory, and strong self-control.[33]

Both medical and psychological tests are continually updated as technology advances and as more is understood about the dynamic limits of normal physiology and about the requirements of the spaceflight regime. All of the laboratory and clinical examinations are performed against a set of "normal" standard values. Those values in turn are updated as the experience base grows. Records are carefully kept regarding the performance of the selection process in screening out medical problems.[34]

The third and final stage of selection takes place at the cosmonaut training center, where a senior medical evaluation commission makes its decisions on the basis of physical and psychological test results. The recommendations are confirmed by the Chief Medical Commission of the USSR, comprised of the leading specialists in clinical and space medicine. In general, candidates are judged unsuitable if disorders are found in nervous, anatomic, or infectious parameters. All serious psychological illnesses are grounds for rejection. If a candidate is highly desirable on the basis of technical capabilities or knowledge, selection may be postponed until at least one year after successful recovery from an abnormal psychological condition. Selection may also be postponed, on an individual basis, to permit recovery from an infectious or other disease.[35]

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[28] Ibid.

[29] Gurovskiy, N. N., et al. Designing the Living and Working Conditions of Cosmonauts. Moscow, Mashinostroyeniye, 1980.

[30] Vorob'yev, Ye.I., and A. R. Kotovskaya. Space Biology and Medicine in Intercosmos Program. Zemlya i Vselennaya, no. 2, March-April 1982, pp. 32-35.

[31] Gazenko, O. G. Cosmic Biology and Medicine, Yesterday and Today. Zemlya i Vselennaya, no. 5, September-October 1983, pp. 4-8.

[32] Bodrov, V. A., et al. Psychological Selection of Pilots and Cosmonauts. In Problems of Space Biology (Vol. 48). Moscow, Izdatel'stvo Nauka, 1984.

[33] Novikov, M. A. The Psychophysiological Selection, Crew Manning, and Training for Space Flight. In Psychological Problems of Space Flight, Moscow, 1979, pp. 196-204.

[34] Lanzerotti, L. J., et al. Soviet Space Science Research (FASAC-TAR-3060). Report prepared by the Foreign Applied Sciences Assessment Center, Science Applications International Corporation, McLean VA, January 21, 1986, pp. V-27-28.

### *Crew Selection*

Distinct from the selection of individual cosmonauts is the selection of crews for specific missions. There are two primary considerations here: suitability on the basis of technical qualifications and experience, and crew compatibility.

Determining qualifications and experience is a relatively straightforward matter, based on previous missions and/or academic background. Crew compatibility issues are more problematical; yet serious problems of crew interaction seem to have emerged in the Soviet space program on long-duration missions, and Soviet scientists are actively seeking and testing selection factors based on compatibility.[36] [37] [38] [39]

Methods are based on experimental psychology. For example, to test their willingness to cooperate and conform so as to accomplish mission goals, cosmonauts are asked to take part in various activities designed to stimulate mutual interaction. One such test is the Mutual Talking Test, which measures the extent to which the heart beats of cosmonauts synchronize while they are working together. The higher the degree of synchronization, at higher pulse rates, the more compatible the individuals are found to be under the stresses of long- term space flight.[40] It is noted, especially by the cosmonauts themselves, that opposites are often compatible—for example, introverts and extroverts.[41] [42] [43] Common-sense approaches such as training, working, and relaxing together over a period of time are often emphasized.

### *Training Process*

#### *Training Facilities*

The center for cosmonaut training is at Star City (Zvezdny Gorodok, 40–50 km outside Moscow). This complex includes the Yuriy Gagarin Cosmonaut Training Center, where much of the technical training takes place. Cosmonauts at the facility include those who are awaiting flight as well as veterans of previous flights who are serving as administrators and instructors.

There are currently approximately 110 members of the cosmonaut corps. About 50 of them are military cosmonaut-pilots, who live "on base", enjoying a standard of housing and general living beyond the reach of most Soviet citizens. The remainder are civilian cosmonaut- researchers who live at the center only when training for a specific flight. About ten of the present cosmonauts are said to be women.[44]

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[35] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 680.

[36] Kidger, N. Salyut Mission Report. Space Chronicle, June 1983.

[37] Ducrocq, A. The Terrible Return. Air et Cosmos, December 18, 1982, pp. 52–63.

[38] Yenyutina, L. Zero Gravity: Its Dangers and Possibilities. Soviet Life, April 1981, p. 33.

[39] Leonov, A. A. Prospects for the Conquest of Space and Psychology. In Psychological Problems of Space Flights. Moscow, Nauka Press, 1979, pp. 35–40.

[40] Yenyutina, L. Zero Gravity: Its Dangers and Possibilities, op. cit.

[41] Sudakov, V. Cosmonaut Ivanchenkov Interviewed on Living Conditions Aboard Salyut Station. In J. W. McBarron II (Ed.) Soviet EVA Operations and Equipment Data, NASA Johnson Space Center, January 28, 1985.

[42] Gor'kov, V. and N. Kon'kov. Cosmonaut Berezevoy's Memoirs on 211-day Space Flight. Aviatsiya i Kosmonavtica, no. 7, July 1983.

[43] Moscow Domestic Service, 0655 GMT, August 10, 1984.

Training facilities at Star City include full-size simulators of the Salyut and Mir space stations, the Kvant astrophysics module, the Soyuz T and TM ferry craft, and a command and control facility.[45] [46] Other facilities (some of them located elsewhere in the Soviet Union) include a water immersion facility for EVA simulation, an Ilyushin Il- 76 aircraft for parabolic flight conditioning, extensive facilities for exercise and physiological stress conditioning (including centrifuges and altitude and isolation chambers), and a planetarium.[47]

It was recently reported that Star City facilities are being expanded to support training for the Soviet space shuttle program. Several new buildings are being constructed, and experienced cosmonauts are now in training for future shuttle missions.[48]

### *Overall Training Approach*

All cosmonauts are trained in four basic areas: (1) spacecraft control, and operation and maintenance of the onboard systems; (2) testing of equipment and performance of scientific/technical activities; (3) conditioning for spaceflight physiological factors; and (4) politics, teamwork, and psychological preparation.[49] The Soviets still adhere to the concept that all cosmonauts should be able to function as both operators and researchers; but (as in the American program) as mission requirements have become more complex and demanding, a differentiation has occurred between the roles of pilot and researcher. Mission-specific training reflects this division of roles.

Cosmonaut training takes place in two stages, generic (basic) training and direct training for a specific mission. Generic training requires 3–5 years for cosmonaut-pilots and 1–2 years for cosmonaut- researchers. Carried out with groups of trainees, it encompasses: theory of cosmonautics; biomedical subjects; physical training; flight dynamics; navigation; astronomy; computer science and applications; ballistics; and group dynamics.[50] Each discipline involves 30–40 hours of classroom instruction. Upon completing the generic training program, cosmonauts undergo personal interviews and course examinations. When this stage of training is completed, crews are formed for future missions.

Direct training for specific missions is conducted on a crew basis. Usually at least two crews are trained simultaneously: the flight crew and the backup crew. All cosmonauts train first as backups before being assigned to a flight crew, and every member of the flight crew has a backup.[51] The training given to prime crews and their backups is considerably more extensive than that which the short-term visiting crews receive.[52] The direct training of prime crews takes 3-4 years. It emphasizes the control of the spacecraft and other equipment, through exercises in various trainers, mockups, and modeling stands. It includes detailed study of the flight program, with simulation of the entire mission and all operations. It also includes study of the onboard and flight documentation as well as training in required experiment techniques and interaction with ground control.

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[44] Canby, T. Y. Are the Soviets Ahead in Space? op. cit., p. 443.

[45] Procedures Training Preceded Soviet Soyuz T-13 Mission. Aviation Week and Space Technology, July 22, 1985, p. 141.

[46] Soviets Train Cosmonauts at Star City. Aviation Week and Space Technology, October 19, 1987, pp. 110–111.

[47] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., pp. 682–685.

[48] Soviets Fly Jet-Powered Space Shuttle Testbed. Aviation Week and Space Technology, October 12, 1987, pp. 22–25.

[49] Nikolayev, A. G. Cosmonaut Training: The New Profession of the 20th Century. Zemlya i Vselennaya, no. 2, March-April 1983, pp. 2–7.

[50] Beregovoy, G. Beregovoy on Cosmonaut Training (interview conducted Apr. 1983). In J. W. McBarron II (Ed.), Soviet EVA Operations and Equipment Data, op. cit.

An inherent problem in cosmonaut training is that simulation of activities on the ground is always an imperfect substitute for actual operations in space. Spacecraft control, EVA, and experiment operation are all impossible to simulate adequately. Consequently, there is a continual emphasis on building in the cosmonaut's mind as reliable a conceptual model as possible of the actual spaceflight conditions.[53]

One significant difference in approach to training, between the USSR and the United States, is that the Soviet program does not rely heavily on preprinted training materials such as systems manuals (as the U.S. program does). Instead, each cosmonaut trainee develops his or her own extensive notes in class, and refers back to these during the mission. French "spationaut" Jean-Loup Chretien flew with the Soviets on a Salyut mission in 1982, was backup Mission Specialist on a U.S. shuttle Spacelab mission in 1985, and is once again in the USSR preparing for a mission to Mir in late 1988. He finds that "the best method in terms of committing the basic elements to memory has been with the training in the USSR."[54] (Chretien noted "some modernization" of the Soviet training procedures since 1982, but reported that the basic philosophy is unchanged.)

### *Physical and Psychological Training*

Training protocols for Soviet cosmonauts demand rigorous physiological and psychological stress training in those areas considered to be critical to the success of the space mission. The overriding objective of all training efforts is to moderate, to the extent possible, the effects of weightlessness on physiological well-being.[55] The physical training of crews takes between 12 and 18 months. It incorporates activities such as running, skiing, swimming, diving, vaulting, rowing, cycling, acrobatics, and weightlifting.[56] The objective of these activities is to improve the functional capacity and reserves of the heart, lungs, vestibular organs, and other physiological systems under increasing load. During this training, cosmonauts are exposed to and learn to overcome not only simulated weightlessness, but also short-term overloads of acceleration and vibration, heat, hypoxia, decompression, and other potential spaceflight factors.

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[51] Ibid.

[52] Lanzerotti, L.J., et al. Soviet Space Science Research, op. cit., p. V-28.

[53] Bogdashevsky, R. B., et al. Objectivization of Basic Elements of the Process of Training the Crew for Spaceflight. In Psychological Problems of Space Flights. Moscow, Nauka Press, 1979, pp. 246-252.

[54] Foreign Cosmonauts Train for Flights on Mir Space Station. Aviation Week and Space Technology, May 11, 1987, p. 105.

[55] Bluth, B. J. Soviet Space Stress. Science 81, Septe,ber 1981, pp. 30-35.

[56] Barchukov, I. Overcoming Weightlessness. Soviet Military Review, no. 6, June 1981, pp. 62-64.

It is generally agreed that adaptation to weightlessness is enhanced by preflight physical conditioning. It is also believed that some types of physical training (e.g., skiing, parachute jumping) play an important role in improving the readiness of a crew to deal with stressful and/or emergency situations.[57] A more controversial issue is to what extent cosmonauts should be conditioned physically. Some believe that the more extensively an individual is conditioned preflight, the greater the deconditioning he or she will undergo in space and the more difficult will be the readaptation upon returning to Earth's environment. (See the following subsection for a more detailed discussion of these matters.)

Physiological and psychological conditioning in the Soviet program are said to be much more rigorous than that to which American astronauts are subjected. But they are now less so than in the early years of the Soviet program, when cosmonauts were subjected to violent centrifugation, intense heat for 24 hours while wearing space suits, ejection from jet aircraft in flight, lengthy confinement in isolation chambers, etc.

Preflight vestibular stress testing is employed in an effort to increase vestibular tolerance and to select cosmonauts who are less prone to space motion sickness. Such testing utilizes both active (strenuous exercise) and passive (e.g., centrifugation, parabolic flight) conditioning techniques.[58] There are consistent reports that such conditioning reduces gastrointestinal distress in the early phase of flight (see next subsection). However, as mentioned previously, its usefulness as a predictor of susceptibility to space motion sickness has not been clearly shown.[59]

To impart an ability to withstand the transverse accelerations encountered during liftoff and other phases of flight, extensive familiarization runs are made in centrifuges. Such exposures produce a significant increase in individual tolerance levels. Centrifugal forces are gradually increased over periodic exposures during a two-month interval, an approach which has been shown to increase tolerance to transverse G forces.[60]

An integral part of acceleration and vestibular training is visual perception training. (Oculomotor functions are thought to play a part in the etiology of space motion sickness). However, training in spatial orientation and visual perception has been deemphasized in cosmonaut-researchers, since they do not have a primary role as pilots.[61]

The cosmonaut training program includes training of the psyche as well as the body. To avert tensions and improve crew performance, considerable time is devoted to behavioral areas. Crew selection is designed to maximize compatibility, as described earlier. Group training is emphasized to facilitate teamwork.[62] Methods of evaluating stress responses are being investigated. These include brain scans, voice stress tests, and changes in circulatory endocrine levels. Eventually, it may become possible to quantify physiological and psychological stress levels and to adjust the environment, work activities, and personal interactions accordingly. In the meantime, experimental psychological monitoring equipment has been placed aboard some Soviet spacecraft to monitor tension and mood changes by voice harmonic analysis and changes in facial expression.[63]

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[57] Makarov, R. Flight Dictates Training. Aviatsiya i Kosmonavtika, no. 2., 1974, pp. 44–45.

[58] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 682.

[59] Lanzerotti, L. J. Soviet Space Science Research, op. cit., p. V–28.

[60] Link, M. M., and N. N. Gurovskiy. Training of Cosmonauts and Astronauts. Journal of Space Biology and Medicine, 1975, p. 438–450.

[61] Saiki, H., et al. Effect of Physical Fitness and Training on Physiological Response to Hypogravity. Acta Astronautica, 1981, pp. 959–965.

Soviet training programs prepare the individual for stresses other than overload or crisis—such as isolation, boredom, and confinement. The Soviet philosophy in this area of training is based not only on the need to endure long periods of monotonous work, but also on the need for cosmonauts to remain flexible and adaptable, able to "shift gears" rapidly in response to potential emergency situations.[64] The unrehearsed EVA performed by the Soyuz TM-2 crew in April 1987 to assist in the docking of the Kvant module to Mir was an example of the kind of flexibility needed.

### ADAPTATION TO SPACE, READAPTATION TO EARTH

Space flight presents several biomedical challenges to human and other terrestrial organisms. Some of these features are inherent in the space environment itself. Chief among these is weightlessness, or zero gravity—more accurately termed "microgravity," since gravitational forces experienced in near-Earth orbit actually average around 10-6 g. Another inherent space environmental factor is ionizing radiation. Ionizing radiation is found in the geomagnetically trapped radiation belts around the Earth (the Van Allen belts), in solar flares, in galactic cosmic radiation (consisting of protons, alpha particles, and heavy nuclei), and in the "secondaries" produced by the collision of ionizing radiation with spacecraft materials. (Non-ionizing radiation is produced by electromagnetic fields associated with the operation of spacecraft systems and equipment).

Some spaceflight factors derive from the requirement for transportation and protection of humans in spacecraft. Habitation aboard a space vehicle, particularly on a long-term basis, presents challenges associated with the design of the spacecraft, the materials employed in its construction (which may generate toxic degradation products), the nature of its onboard life support systems, the sociology of crew interaction, and the psychological stresses imposed by many aspects of living and working in space. Vibration and noise also affect space travelers variously in different stages of a mission.

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[62] Barchukov, I. Leonov on Cosmonaut Training, op. cit.

[63] Bluth, B. J. Soviet Space Stress, op. cit.

[64] Myasnikov, V.I., and O.P. Kozarenko. Prevention of Psychoemotional Disturbances During Long Term Space Flights by Means of Psychological Support. Kosmicheskaya Biol. i Aviak. Medit., No. 2, 1981, pp. 25–29.

Of all these spaceflight factors, only one—microgravity—has produced substantial physiological change in the human organism, in missions flown to date. For that reason, its effects receive primary attention in both the Soviet and U.S. space life sciences programs.

### *Adaptation to Microgravity*

When gravity is absent, physical mechanisms come into play that are aimed at establishing an adequate balance between the body and the new environment.[65] Changes occur in the cardiovascular system, the vestibular organs associated with balance and orientation, the muscles and bones, and blood and other body fluids. Some of these changes are short-term (i.e., they occur soon after entry into microgravity), while others are long-term changes occurring over a period of weeks, months, or longer.

The physiological adaptive changes are appropriate and healthy. Terrestrial organisms have evolved and lived under a continuous force of 1 g. The removal of gravity eliminates the natural deformation of bodily organs and the mechanical tension among body structures. This in turn leads to a change in sensory input, to the loss of hydrostatic pressure in blood and other fluids, and to the loss of the accustomed weight load on the musculoskeletal system.[66] Thus, some physiological systems become overloaded, while the body's support systems are underloaded. The physiological changes are a direct response to those changes in the internal environment of the body. For the most part they are self-limiting after stasis is achieved, and reversible after readaptation to Earth gravity. But several of the adaptive responses are of concern to Soviet space medicine specialists, particularly in the context of very long-duration missions such as interplanetary flight.[67]

### *Cardiovascular Adaptation*

Almost immediately upon entering the weightless state there is a partial shift of blood and other fluids from the lower extremities, where they are normally retained by gravity, into the chest and head. The resulting increase in central blood volume triggers reflex mechanisms under the control of the central nervous system to excrete the "excess" fluid through the kidneys. At the same time there is an increase in heart rate and in the stroke volume of the heart, to compensate for a decrease in the diastolic volume of the heart. The amount of blood reaching the lower extremities decreases by as much as 10 percent. These responses represent an attempt to restore a stable dynamic state.[68] The changes represent a deconditioning of the functional capacity of the cardiovascular system. While the effects of this deconditioning are manifested upon return to Earth, they are reversible after a period of readaptation (see following subsection).

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[65] Gazenko, O.G. Man in Space. Kosmicheskaya Biol. i Aviak. Medit., *18*(1), 1984, pp. 3–8.

[66] Gazenko, O.G., et al. Man in Space Flight, op. cit.

[67] Garshnek, V. Soviet Manned Space Flight: Progress Through Space Medicine. In Proceedings of the symposium, Working in Orbit and Beyond: The Challenge for Space Medicine, June 20–21, 1987, Georgetown University Continuing Medical Education Program. Washington, DC: American Astronautical Society (in press).

[68] Yegorov, A. D., et al. Cardiovascular Studies. In Results of Medical Investigations on Salyut-6 -Soyuz. Moscow, Nauka Press, 1986, pp. 89–111.

The cardiovascular system appears to be studied more intensively by the Soviets than any other body system.[69] Their long-term missions entail a more extensive cardiovascular adaptation to space flight than do the shorter U.S. missions to date, so they have heretofore devoted more effort than the U.S. has to studying that adaptation process and finding ways to control it (see subsections below dealing with countermeasures).

### *Vestibular Alterations*

Beginning almost immediately after insertion into microgravity, and continuing for 2-4 days (5 at the maximum), many space travelers experience a cluster of symptoms that are collectively known as "space motion sickness", or SMS. (American space medicine specialists prefer the term "space adaptation syndrome".) Approximately 50 percent of all crewmembers experience SMS symptoms, which include headache, listlessness, dizziness, sensitivity to noise, spatial illusions, nausea, and—in about half the cases—vomiting. Rapid head movements appear to exacerbate the symptoms.[70] [71]

Despite considerable research by Soviet and American scientists, the causes of SMS are not yet well understood. There is a range of competing theories about its etiology. Most American space medicine specialists and some Soviets ascribe SMS to the "sensory conflict" that develops when the brain attempts to process conflicting information from different sources.[72] According to this theory, removal of gravity eliminates the neural signals normally generated by the otolith organ in the inner ear. Conflicting information from the eyes and from pressure and stretch receptors in the skin and muscles results in a dilemma which the brain attempts to resolve by producing the symptoms noted above.[73]

Until recently, the headward shift of body fluid was thought by many to be at fault.[74] Others believe that SMS results from reinterpretation of otolith signals by the brain.[75] Many Soviet specialists now believe that variations in the function of the vestibular apparatus and related sensory systems in microgravity are responsible.[76] [77]

SMS is the only adverse effect of space flight, noted to date, that has significantly impaired crew effectiveness during the first few days of a flight.[78] For this reason it has received considerably more attention and concern within the U.S. space program than in the Soviet program. In U.S. space shuttle missions, SMS presents a problem for as much as half the mission for affected astronauts. Because Soviet space station missions are longer, they are able to sidestep much of the problem by minimizing intensive work during the early phase of the missions, until adaptation has occurred.[79]

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[69] Lanzerotti, L. J., et al., Soviet Space Science Research, op. cit., p. V-12.

[70] Kozlovskaya, I. B., et al. Adaptation Mechanisms in the System of Vestibulo-oculomotor Interaction to Changes in Vestibular Function. *In* Physiologic Adaptation of Man in Space, 7th International Man in Space Symposium, Houston TX, February 10-13, 1986, pp. 1-2.

[71] Johnson, P. C., Jr. Space Medicine. American Scientist, September-October 1984, pp. 495-497.

[72] Nicogossian, A.E. and J.F. Parker, Jr. Space Physiology and Medicine (NASA SP-447). Washington, U.S., Govt. Print. Off., 1982, p. 146.

[73] Kohl, R.L. Sensory Conflict Theory of Space Motion Sickness: An Anatomical Location for the Neuroconflict. Aviation, Space, and Environmental Medicine, *54*(5), 1983, pp. 464-465.

[74] Yakovleva, V.I., et al. Results of Studies of Vestibular Function and Spatial Perception in the Crews of the First and Second Expeditions Aboard Salyut-6 Station. Kosmicheskaya Biol. i Aviak. Medit., no. 1, 1981, pp. 19-23.

[75] Parker, D. E., et al. Space Motion Sickness Prophylactic Adaptation Training: Preliminary Studies of Trainer Prototypes. *In* Abstracts of Papers, 36th International Astronautical Congress, Stockholm, Sweden, October 7-12, 1985, pp. 232-233.

[76] Yegorov, A. D. and E. M. Yuganov. Labyrinthine and Extralabyrinthine Mechanisms of Motion Sickness. Kosmicheskaya Biol. i Aviak. Medit., *19*(2), 1985, pp. 4-11.

[77] Grigoriev, A. I., et al. Neurohumoral Mechanism of Space Motion Sickness. Presented at 37th Congress of the International Astronautical Federation, Innsbruck, Austria, October 4-11, 1986.

The search for countermeasures to SMS has been hampered by the uncertainty over its causes. A wide variety of pharmacological agents have been tried in both the U.S. and Soviet programs, but with only limited success (see further discussion under "Other Countermeasures").[80] Preflight vestibular conditioning, as in rotating chairs and underwater training, has been shown to be partly effective in speeding inflight adaptation; the timecourse of adaptation is also usually shorter for those with previous missions.[81] Preselection to screen out those with susceptibility to SMS would be an ideal solution. However, all selection methodologies, including susceptibility to ground motion sickness or seasickness, have thus far proven ineffective.[82]

### *Muscle and Bone Changes*

Among the most noticeable physiological adaptive changes in space flight are a deterioration of certain muscle groups and a progressive loss of calcium and other minerals from bone. In both cases, the absence of gravitational weight loading is the precipitating factor, and countermeasures focus primarily on restoring tension and weight forces through exercise and other means.[83]

The underloading of muscles—particularly those that form and maintain posture—results in partial atrophy, loss of mass in leg and back muscles, and a decrease in leg muscle tone. More generally, there are substantial changes in motor function, typified by changes in movement patterns and decreased motor coordination.[84] (These changes are reflected in postflight difficulties in maintaining equilibrium.) After about one month in space, an individual is said to lose approximately 20 percent of leg muscle strength and 10 percent of arm muscle strength, even with exercise.[85] The loss in circumference of the legs often amounts to several centimeters. However, the losses do not continue at these rates if an adequate exercise routine is followed, and they are reversible upon return to Earth.[86]

A more serious problem is bone degeneration. This condition is produced by increased excretion of calcium and phosphates in urine, as well as losses of nitrogen and hydroxyproline.[87] The average calcium loss from the bones is about 0.5 percent per month overall, with as much as a 5 percent loss in certain weightbearing bones such as the heel and shin.[88] Some U.S. specialists believe that only about two-thirds of the calcium lost through disuse is recoverable after return to Earth. Thus, if this rate of loss were unchecked and continuous, for each 90 days spent in space a crew member could expect a permanent loss of 0.5 percent of the entire skeleton and about 5 percent in certain critical bones.[89] Losses of this magnitude would certainly increase the risk of fracture, especially upon return to Earth and as the cosmonaut ages.[90]

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[78] U.S. Congress. Soviet Space Programs: 1976–1980, op. cit., p. 699.

[79] Lanzerotti, L. J. Soviet Space Science Research, op. cit., p. V-15.

[80] Shaskov, V. S. and V. V. Sabayey. Pharmacological Agents for the Prevention and Treatment of Motion Sickness. Kosmicheskaya Biol. i Aviak. Medit., 1981, pp. 9–18.

[81] Berry, C. A. Physiological and Psychological Parameters of Life in

[82] Nicogossian, A. E. and J. F. Parker, Jr. Space Physiology and Medicine, op. cit., p. 151.Space Stations, op. cit., p. 26*

[83] Ibid., pp. 186–209.

[84] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[85] Johnson, P. C., Jr. Space Medicine, op. cit., p. 497.

[86] Lanzerotti, L. J., et al. Soviet Space Science Research, op. cit., p. V-19.

[87] Gazenko, O.G., et al. Fluid-electrolyte Homeostasis and Space Flight. *In* Problems of Space Biology (v. 54). Moscow, Nauka Press, 1986.

It is not known for certain whether the loss of bone minerals levels off after a certain period of time in space. Data are as yet inconclusive and highly variable across individuals; however, it is clear that the losses can be substantial after six months in space. Even rigorous exercise appears to have only a partly ameliorative effect.[91] Table 12 gives the results of bone mineral loss studies aboard Salyut 6.

As in the case of SMS, the physiological mechanism underlying disuse osteoporosis in space is not known. It may be that calcium is lost from the bones at a faster than normal rate, or that new calcium is fixed in the bones at a slower than normal rate. The Soviets have devoted more research attention to this problem, and to its possible countermeasures, than has the United States. They employ ground-based microgravity simulations such as long-term bedrest (in humans) and immobilization (in animals) in concert with postflight measurements of cosmonauts by means of x-ray photometry and photon absorptimetry, in an attempt to understand better this factor which could potentially limit the duration of piloted missions in space.[92]

TABLE 12.—RESULTS OF PRE- AND POST-FLIGHT MEASUREMENTS OF THE HEEL BONE IN SALYUT 6 COSMONAUTS

[Flight duration and change in mineral content]

| | Days | Percent |
|---|---|---|
| Crewmember: | | |
| A | 140 | −3.0 |
| B | 140 | −19.8 |
| C | 175 | −9.8 |
| D* | 175 | −3.0 |
| E | 175 | −9.6 |
| D* | 185 | −4.1 |
| G | 75 | −0.9 |
| H | 75 | −3.2 |

*Same cosmonaut, with eight months intervening between missions.

Source: Stupakov et al., Kosmicheskaya Biol. i Aviak. Medit., 18, 1984, p. 33–37.

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[88] Volozhin, A. I. Mechanisms of Osteodystrophy in Weightlessness. Pathology, Physiology, and Experimental Therapy, no. 1, 1984, pp. 19–27.

[89] Johnson, P. C., Jr. Space Medicine, op. cit., p. 497.

[90] Parfitt, A. M. Bone Effects of Space Flight: Analysis of Quantum Concept of Bone Remodeling. Acta Astronautica, *8*, 1981, pp. 1083–1090.

[91] Gazenko, O. G., et al. Fluid-electrolyte Homeostasis and Space Flight, op. cit.

[92] Gazenko, O. G., et al. Man in Space Flight, op. cit.

### *Hematologic Changes*

As noted above, the headward shift of body fluids in microgravity causes an adaptive excretion of fluids resulting in a reduction of the volume of fluids. Thus, during even a brief space flight of 7–8 days, an individual loses 10–20 percent of the circulating blood volume. This is manifested as a reduction in both plasma volume and red blood cell count. Erythropoietin content in the blood also decreases, cutting back the production of new red cells within the bone marrow. Certain changes in the shape of red cells produced in space have also been noted.[93] [94]

In the early years of space flight, hematologic changes were viewed with some concern by both Soviet and American space medicine specialists. However, that concern has largely abated. None of these changes appears to have an adverse effect on cosmonaut health inflight, and all of them are reversible within about a week postflight.[95]

### *Postflight Readaptation*

The first decade of piloted space flight indicated that, while certain biomedical effects of such missions were evident both inflight and postflight, they were not a cause for concern.[96] The 1970 flight of Soyuz 9 shook that optimism. After this 18-day mission, nearly double the duration of the previous longest Soviet mission, the two cosmonauts returned to Earth in poor condition. They exhibited pronounced orthostatic intolerance (i.e., had trouble standing upright) and had to be carried from their spacecraft on stretchers. They required 11 days of postflight readaptation to gravity before the most obvious difficulties abated.[97]

Since then, it has been universally recognized by space medicine specialists that all space travelers experience difficulties, to varying degrees, in the different bodily systems as a result of space flight.[98] The most common symptoms and observations are the following:

Weakness and fatigue
Loss of muscle mass and tone
Reduced bone mineral content and mass
Dizziness and vestibuhar discomfort with sharp head movements
Problems in perceiving the spatial orientation of the body
A feeling of increased weight of the body and objects
Decrease in orthostatic stability
A tendency toward fainting
Limitations in motor function and coordination
Increased perspiration
Tachycardia (increased heart rate)
Decrease in cardiac stroke volume and blood ejection time
Reduced blood volume and red blood cell count

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[93] Burnazyan, A. I. and O. G. Gazenko. Handbook on Space Biology and Medicine (3rd ed.). Moscow, Medizina, 1983, pp. 41–44.

[94] Johnson, P. C., Jr. Space Medicine, op. cit.

[95] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[96] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., pp. 460–461.

[97] Ibid.

[98] Gazenko, O. G. Results and Prospects of Physiological Research During Space Flight. Vest. Akad. Med. Nauk SSSR (Moscow), no. 4, April 1984, pp. 7–11.

The most immediately pressing problems are those associated with standing and walking, and with dizziness and fainting. In long-term missions, the readaptation process actually begins 2–4 weeks before the return to Earth, with cosmonauts being subjected to a regimen of negative pressure applied to the lower half of the body in order to reestablish vascular tone. During the final two days in space, they are required periodically to drink about 400 milliliters (ml) of saline solution to build up the blood plasma volume. An "antigravity suit" is also worn to prevent blood pooling in the legs. These measures are all designed to reduce orthostatic intolerance during and immediately after descent.[99] (See "Other Countermeasures," below, for further discussion.)

After long-term missions, considerable orthostatic intolerance is seen in the first day postflight. The antigravity suit continues to be worn. On the second or third day, crewmembers are able to walk with assistance. (The crew of the 237-day mission in 1984 did so after two days.) Light physical work is possible on the fourth day.[100] However, even by the fourth day vestibular function does not always normalize, and it may require seven days or more for red blood cell count to return to normal.[101]

Given current inflight countermeasures programs, complete recovery of cosmonauts now takes about three weeks.[102] However, recovery of lost muscle mass may take longer. Some cardiovascular parameters also take longer to recover, but all are normal by 3–12 months postflight. Lost bone mineral is never recovered fully.[103]

After long-duration flights, supervised rehabilitation includes special diets and "functional therapy," consisting of dosed walking, swimming, massages, hot baths and heat treatments, and even mountain climbing.[104] Postflight medical analyses continue for up to a month. They include extensive blood and urine analysis, bone/muscle tomography, and vestibular tests on rotating chairs and parallel swings.[105]

### *Summary*

Perhaps the definitive Soviet view of human experience and potential for adaptation to spaceflight factors and readaptation to Earth was given in October 1987 by Dr. Oleg Gazenko and some of his most eminent colleagues:

> The results of medical investigations performed in short- and long-term flights have clearly demonstrated that man can adequately adapt to the weightless state and efficiently work for as long as 8 months. Changes in various physiological systems were adaptive in character, consistent with the acting factors, reversible, and did not influence the flight program fulfillment. Postflight responses were largely determined by the scope and intensity of the countermeasures used. They were also

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[99] Garshnek, V. Soviet Manned Space Flight: Progress Through Space Medicine, op. cit., pp. 11–12.

[100] Ibid.

[101] Johnson, P. C., Jr. Space Medicine, op. cit., pp. 496–497.

[102] A Doctor in Space. Soviet Life, Apr. 1985. (Interview with Dr. Oleg Atkov).

[103] Al'bats, Y. Academician Gazenko Interviewed on Medical Issues in Manned Spaceflight. Nedelya, no. 45, 1980, pp. 10–11.

[104] Krupina, T. N. et al. Combined Rehabilitation and Therapeutic Measures in Space Medicine. Sovietskaya Meditsina, no. 12, 1981. pp. 3–8.

[105] Garshnek, V. Soviet Manned Space Flight: Progress Through Space Medicine, op. cit., p. 12.

related to the individual characteristics of the crewmembers and, to a certain extent, flight time. In summary, the basic physiological systems that could be adversely affected by spaceflight factors did not develop significant changes which could prevent further continuous increase in flight duration.[106]

## FLIGHT DURATION

From a biomedical standpoint, the goal of Soviet space activities has been to extend human presence in space to the longest possible duration.[107] For over a decade the Soviets have been testing and extending the limits of human endurance of spaceflight conditions. This effort began in earnest aboard the Salyut 6 station (launched in 1977), with a series of missions lasting 96, 140, 175, 185, and 75 days. It continued on Salyut 7, and is still being pursued today aboard the Mir space station. At the same time, the Soviets have been collecting data from ground-based studies and flight experiments involving animals and insects. Several overlapping but distinct purposes can be discerned in this work: to find what the limits are for the different physiological and psychological systems; to understand the mechanisms of adaptation and readaptation; to identify and perfect countermeasures to space deconditioning; and to define (if possible) the optimal duration of space missions. An underlying purpose has been to determine whether very long-duration flights (e.g., to Mars) are feasible.

With the flight of Yuriy Romanenko in 1987, the Soviets have now pushed the "envelope" of long-duration human presence in space to 326 days.[108] Many expect the crew of the next long-duration mission to spend at least a year in space.[109] A three-man crew flew for 8 months aboard Salyut 7 in 1984. (It is possible that cosmonaut Vasyutin's sudden illness in 1985 cut short what would have been a very long-term flight for Viktor Savinykh.) Results to date are very encouraging to Soviet space medicine specialists.[110] However, countermeasures are essential to long-duration flight; the flight of Soyuz 9 in 1970 suggested to the Soviets that 18 days is the maximum time that humans can spend in space without resorting to countermeasures to deconditioning. The Soviets assert that, with adequate countermeasures, it is possible for a crew returning from 8 months in space to show no greater signs of deconditioning than those seen after a 3-month mission.[111] Several cosmonauts have undergone repeated long-duration flights, as shown in Table 13. No evidence of adverse consequences has been seen; indeed, repeated space flight even appears to improve vestibular adaptation.[112]

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[106] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[107] Lanzerotti, L. J. et al. Soviet Space Science Research, op. cit., p. V–35.

[108] On December 3, 1987, it was reported that Romanenko had lost 15 percent of lower leg muscle volume; was obviously tired; and his work schedule had been reduced to 4 hours per day (versus the normal 8 hours). Although his sleep cycle was increased to 9 hours per day, he maintained the 2 hour per day exercise regimen. TASS, 0834 GMT, December 3, 1987. Postflight data were not available at press time.

[109] Soviets to Extend Duration of Manned Missions (quoting Dr. Anatoliy Grigoriev). Aviation Week and Space Technology, October 19, 1987, p. 116.

[110] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[111] Gazenko, O. G., et al. General Mechanisms of Changes of Man's Vital Functions and Adaptation to Prolonged Weightlessness. Presented at the 36th Congress of the International Astronautical Federation, Stockholm, Sweden, October 7-12, 1985.

[112] Kozlovskaya, I. B., et al. Adaptation Mechanisms in System of Vestibulo-oculomotor Interaction to the Changes of Vestibular Function, op. cit.

Time elapsed between such flights does not appear to have significance, as long as there is sufficient time for recovery.[113]

TABLE 13.—REPEATED LONG-DURATION SPACE MISSIONS

| Cosmonaut | First mission | Flight duration | Time between misisons | Second misison | Flight duration | Total |
|---|---|---|---|---|---|---|
| Ryumin | 02/25/79–08/19/79. | 175 d | 234 d (~8 mos) | 04/09/80–10/11/80. | 185 d | 360 d |
| Kizim [1] Solovyev | 02/08/84–10/02/84. | 237 d | 425 d (~14 mos) | 03/13/86–07/16/86. | 125 d | 362 d 362 d |
| Romanenkob [2] | 12/10/77–03/13/78. | 96 d | 8 yrs 11 mos | 02/05/87–12/29/87. | 326 d | 322 d |
| Grechko | 01/09/75–02/07/75. | 30 d | 2 yrs 10 mos | 12/10/77–03/16/78. | 96 d | 126 d |

[1] Kizim also participated in a 13-day visiting mission to Salyut 6 in 1980, giving him an overall total of 375 days in space.
[2] Romanenko also participated in a visiting mission to Salyut 6 in 1980, giving him a cumulative total of 431 days.

Prepared by Courtland S. Lewis for CRS.

However, there is no question that long-duration space flight—at least in its present-day form—is arduous and difficult. The quarters are cramped and not especially comfortable, the workload is heavy and monotonous, and the isolation is extreme. There have been problems of crew interaction.[114] Cosmonauts have been reported as saying that they are eager to go into space the first time, but find themselves hesitant to make a second long-duration trip.[115] Romanenko, a very experienced space traveler, reported at about the 8-month point in his record 1987 flight that "Fatigue makes itself felt. . . . I never used to notice noise from the fans at all, but now it sometimes wakes me up at night. Sometimes I don't fall asleep right away in the evening, or I wake up in the middle of the night and then I'm not myself in the morning." [116]

Based on past Soviet missions, some believe that the optimal working time for a human being in orbit is 3–4 months: about 1 month for adaptation, with another 2–3 months before productivity declines.[117] In fact, crews report that they prefer longer flights because work performance becomes more efficient and because there is then time to deviate from the preestablished program to follow interesting lines of development.[118] Nevertheless, as Cosmonaut Berezevoy noted, almost plaintively, ". . . the longer you stay in orbit the more you value normal life on Earth." [119]

At present, the outlook for continued increases in mission duration is as expressed by Oleg Gazenko above—the physiological effects of long-duration flight appear to be acceptable if appropriate countermeasures are followed. Soviet specialists are generally confident that missions of up to a year are tenable.[120] However, there is a caveat: Gazenko notes that without adequate countermeasures, bone calcium losses could become a limiting factor for further increases in mission duration.[121] U.S. scientists are even more concerned that calcium losses might not level off with time, and most believe that a more effective countermeasure will be needed.[122] This would be a particular concern in the context of a mission to Mars, with its one-third Earth gravity, and zero gravity during the trip to and from the planet. Psychological factors— isolation, group interaction, and crew performance—are also viewed as increasingly important for such missions.[123]

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[113] Gazenko, O.G., et al. Major Medical Results of the Salyut 6—Soyuz 185-day Space Flight. Presented at the 32nd Congress of the International Astronautical Federation, Rome, Italy, 1981, pp. 275-293.

[114] Gor'kov, V. and N. Kon'kov. Cosmonaut Berezevoy's Memoirs on 211-day Space Flight, op. cit.

[115] The Happiness Factor. Space World, November 1983, p. 16.

[116] Ivakhnov, A. Cosmonaut Romanenko Complains of Fatigue After Record Time in Space. Izvestiya, no. 275, October 2, 1987, p. 6.

[117] Konalov, B. Man and Space: Why the Route to the Stars is a Thorny One. Nedelya, no. 41, October 12–18, 1987. pp. 7–9.

[118] Space Exploration Serves Mankind: A "Soviet Life" Round Table Discussion. Soviet Life, November 1985, pp. 15–17, 48–49.

[119] Gor'kov, V. and Kon'kov, N. Cosmonaut Berezevoy's Memoirs on 211-day Space Flight, op. cit.

## EXERCISE AS A COUNTERMEASURE

After the initial piloted space flights proved that humans could survive in the space environment, the flight of Soyuz 9 in 1970 brought in its wake the first serious concern about the deconditioning effects of space flight. Ironically, this was the first Soyuz mission on which exercise was performed; the primary mission of Soyuz 9 was to examine the biomedical consequences of long-term flight, and exercise was an experimental parameter.[124] Since that time, the Soviets have become thoroughly convinced of the effectiveness of exercise in reducing spaceflight physiological deconditioning (i.e., minimizing the adaptation to microgravity) and, thereby, easing the readaptation to Earth gravity. It is therefore the most important *countermeasure* to spaceflight deconditioning—the "backbone of prophylactic measures." [125]

Within the confines of a spacecraft, exercise is the most cost- effective and practical means of restoring weight forces on the body and simulating Earth-normal physical movements, stresses, and physiological system interactions.[126] It helps to maintain overall muscle mass and strength. By stressing the heart and activating "venous pumps" in the peripheral muscles, it helps protect against cardiovascular deconditioning. It stimulates certain nervous receptor groups, helping to maintain motor function. And it helps to control changes in protein metabolism and gas exchange.[127] [128] It helps to keep cosmonauts in good overall health and to maintain high work efficiency.[129] Some researchers believe that exercise is an effective countermeasure to the loss of calcium from bone. But its primary objective is to prevent muscle and cardiovascular deterioration.[130] Experience to date has amply demonstrated the effectiveness of exercise in this area.[131]

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[120] Garshnek, V. Soviet Manned Space Flight: Progress Through Space Medicine, op. cit., p. 13.

[121] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[122] Berry, C. A. Physiological and Psychological Parameters of Life in Space Stations, op. cit., p. 24.

[123] Myasnikov, V. I. Mental Status and Work Capacity of Salyut-6 Station Crew Members. Kosmicheskaya Biol. i Aviak. Medit., 17(6), 1983, pp. 22-25.

[124] U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. Soviet Space Programs, 1966-70 (Ch. 6—Program Details of Manned Flights). Staff report, 92nd Cong., 1st Sess., December 9, 1971. Washington, U.S. Gov. Print. Off., 1971, p. 238.

[125] Grigoriev, A. I., et al. Means and Methods for Preventing the Undesirable Effects of Weightlessness. In (N. N. Gurovskiy, Ed.) Results of Medical Research Performed on Board the Salyut-6-"Soyuz" Orbital Scientific Research Complex. Moscow, Nauka Press, 1986, pp. 125-145.

[126] Nicogossian, A. E. and J. F. Parker, Jr. Space Physiology and Medicine, op. cit., p. 265.

[127] Gazenko, O. G. Results and Prospects of Physiological Research During Spaceflight, op. cit.

[128] Gazenko, O. G., et al. Man in Space Flight, op. cit.

[129] Kidger, N. Salyut 6 Mission Report—Pt. 2. Spaceflight, March 3, 1980, pp. 109-120.

As Soviet space missions have increased, the length and frequency of cosmonaut exercise regimens has also increased. By the time of the six-month Salyut 6 missions in 1979–1980, the exercise routine consisted of two exercise periods per day totalling 2 to 2½ hours per day. The current program is of about the same length. (This time includes the time required to set up and put away the exercise equipment, and to conduct personal hygiene.)[132] Cosmonauts exercise 6 days per week.

Exercise devices aboard the Soviet space stations include a veloergometer (bicycle ergometer) rated for increasing physical load, a treadmill, and bungee cord chest expanders for isometric exercise. The exercise period is generally divided equally between the veloergometer and the treadmill (running at a rate of about 8–9 km/hr), with the isometric devices optional.[133] In addition, a "Penguin suit" is worn during exercise and waking hours. This is an elasticized "constant-loading" garment which opposes movement, thus placing an axial load on the musculoskeletal system.[134] Cosmonauts are monitored telemetrically from the ground, not only for the load utilized and distance covered on the treadmill, but also for vital signs during exercise.[135]

Performance of the exercise regimen is given priority over most non-emergency operations, in Soviet space missions. Cosmonauts are allowed some freedom to develop an individualized program (varying the frequency, duration, and mix of exercises performed).[136] Even still, most cosmonauts apparently dislike conducting onboard exercise. They complain that it is monotonous, tiring, and uncomfortable (perspiration clings to the body in microgravity, and only small absorbent towels are used for hygiene after most sessions). Some cosmonauts must be reminded and exhorted frequently by Flight Control to carry out their exercises.[137] [138] An apparent exception is cosmonaut Romanenko, who was praised for following his workout schedule during his 1987 record-breaking flight.[139]

The Soviets are still studying exercise programs and equipment in an effort to determine the optimal time and techniques. In the Soyuz T-10/T-11 mission to Salyut 7, the exercise time was reduced from 2½ hours to 2 hours, while new exercises were introduced that were described as more intensive and strenuous. The experimental regimen, supervised by the onboard physician, Oleg

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[130] Lanzerotti, L. J. Soviet Space Science Research, op. cit., p. V–19.

[131] Gazenko, O. G., et al. Major Medical Results of the Salyut 6-Soyuz 185-day Space Flight. Presented at the 32nd Congress of the International Astronautical Federation, Rome, Italy, September 6–12, 1981.

[132] Sulzman, F. NASA Life Sciences Division. Personal communication, October 26, 1987.

[133] Ibid.

[134] Nicogossian, A. E. and J. F. Parker, Jr. Space Physiology and Medicine, op. cit.

[135] Garshnek, V. Soviet Manned Space Flight: Progress Through Space Medicine, op. cit.

[136] Kidger, N. Salyut 6 Mission Report—Pt. 3. Spaceflight, 22, April 4, 1980, pp. 146–154.

[137] Gor'kov, V. and N. Kon'kov. Cosmonaut Berezovoy's Memoirs on 211-day Space Flight, op. cit.

[138] Soviets to Extend Duration of Manned Missions. Aviation Week and Space Technology, op. cit. [Interview with A. Grigoriev].

[139] Ibid.

Atkov, was called "Sport." [140] During the same long-term mission, a visiting cosmonaut, Volk, did not exercise. This was described as an experiment, with Volk as the control and Atkov monitoring him.[141] (There was also some suggestion that Volk did not exercise because he was taking anti-SMS medication.)

## OTHER COUNTERMEASURES

Although exercise receives the most attention in the Soviet program, there are also other countermeasures to various aspects of spaceflight adaptation and deconditioning. Taken together, the countermeasures form an ensemble used to maximize health and productivity in space and to reduce the problems of readaptation back on Earth.

### *Physical Countermeasures*

Lower body negative pressure (LBNP) is used to partially reverse the headward shift of fluids in microgravity, thereby simulating the terrestrial pull of gravity on blood and helping to maintain Earth- normal cardiovascular condition. It is applied by means of the "Chibis" (Spring Sparrow) vacuum suit worn over the legs and lower trunk. During flight the Chibis is worn for short periods for tests. Its more important use is to prepare the cardiovascular system for return to gravity. During a 2–4 week period before the end of a mission the Chibis is worn every few days for a set period of time (usually 20 minutes). The Chibis is also worn during exercise in the last several days. In the final 2 days before deorbit, the exposure to LBNP is extended to about 50 minutes.[142] During this phase, cosmonauts also drink about 400 ml of water with 3 gm of sodium chloride while undergoing LBNP; this done 3 times on the final day. The purpose of this "water-salt loading" is to increase circulating blood volume and restore orthostatic tolerance under gravity.[143]

Immediately before descent, an "antigravity suit" is donned. This garment has a function roughly opposite to that of the Chibis suit: It is intended to create pressure in the lower body, thereby preventing the pooling of blood in the extremities during reentry and immediately postflight. It has been shown to improve venous return and orthostatic stability postflight.[144]

On recent missions different designs of a leg bracelet have been tested. These pneumatic garters ("Pneumatik" and "Braslet") are designed to retard the flow of blood to the upper body. They have proven helpful, especially during the early phase of adaptation when the rush of blood to the head is intense.[145] The Soviets use electrical stimulation of various muscle groups in an effort to reduce disuse atrophy of muscle tissue.[146]

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[140] TASS Reports Cosmonauts' Beginning Preparations for Return. Izvestiya, September 26, 1984, p. 6.

[141] Ivakhnov, A. Commentary on Salyut-7 Superpure Substance, Adaptation Experiments. Isvestiya, no. 204, July 22, 1984, p. 3.

[142] Gazenko, O. G., et al. Major Medical Results of the Salyut 6 -Soyuz 185-day Space Flight, op. cit.

[143] Garshnek, V. Soviet Manned Space Flight, op. cit.

[144] Gazenko, O. G., et al. Major Medical Results of the Salyut 6 -Soyuz 185-day Space Flight, op. cit.

[145] Moscow Domestic Service, 0655 GMT, August 10, 1984.

Two devices are used specifically as countermeasures to space motion sickness. The "Cuban Boot" is a sandal-like device which can be inflated like a blood pressure cuff to as much as 60 mm Hg. Some cosmonauts have found that the resulting pressure on the soles of their feet relieves spatial illusions and motor disturbances to some extent. The mechanisms of action are probably neurophysiological, but are not precisely known.[147] A "neck pneumatic shock absorber" is also used. This device consists of a soft cap secured by nonstretching straps attached to the shoulders, and with built-in rubber cords. It is designed to limit the head movements that have been found to worsen SMS symptoms. First used on Salyut 6, it was found to be an effective countermeasure.[148] [149]

### *Drugs*

Pharmacologic protection has long been an active avenue of research in the Soviet space program, as it has in the U.S. program. Drugs are employed as countermeasures to SMS, cardiovascular deconditioning, bone mineral loss, and radiation damage. Such prophylactic and therapeutic drugs are included in the onboard medical kits along with emergency medications.[150]

The anti-motion sickness drugs are generally central anticholinergic-acting preparations such as scopolamine. Antihistamines (e.g., Dramamine), neuroleptics, and barbiturates have also been tried. However, all have side-effects and/or other drawbacks (e.g., inducing drowsiness), and few are very effective.[151] American space medicine specialists agree with their Soviet counterparts that better preparations to combat SMS must await a better understanding of the mechanisms of the disorder itself.[152]

Soviet researchers are more in favor than their American counterparts are of using drugs to combat cardiovascular deconditioning. (The longer duration of Soviet flights has also afforded a greater opportunity for experimentation in this area.) Drugs have been employed to control microgravity-induced cardiovascular disturbances, to improve adrenergic regulation of blood circulation, to normalize water-salt metabolism, and to control fluid loss.[153] Efforts to find pharmaceutical countermeasures to bone demineralization have not been completely successful—in large part because the physiological mechanism is still unknown. However, certain diphosphonate compounds have shown promise.[154]

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[146] Nicogossian, A. E. and J. F. Parker, Jr. Space Physiology and Medicine, op. cit. Nicogossian argues that the "electrostimula -tion" relies partly on biofeedback mechanisms.

[147] Kozlovskaya, I.B., et al. Effect of Support Stimulation of the Feet on the Motor Apparatus in Weightlessness and Immersion. Abstract of paper presented at the 14th Meeting of Socialist Countries and Symposium of the Working Group on Space Biology and Medicine, Varna-Druzhba, April 19–26, 1981, p. 38.

[148] Report on the Watch in Space. Izvestiya, September 1982, p. 2.

[149] Matsnev, E. I., et al. Space Motion Sickness: Phenomenology, Countermeasures, and Mechanisms. Aviation, Space, and Environmental Medicine, April 1983, pp. 312–317.

[150] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., pp. 690–692.

[151] Matsnev, E. I., et al. Space Motion Sickness, op. cit.

[152] Lanzerotti, L.J., et al. Soviet Space Science Research, op. cit., p. V–16.

[153] Nicogossian, A. E. and J. F. Parker, Jr. Space Physiology and Medicine, op. cit.

[154] Garshnek, V. Soviet Manned Space Flight, op. cit.

The Soviets have expressed far more concern with "radiobiology" in the context of space travel than are their U.S. counterparts. A number of radioprotective drugs have been tested on animals and humans; but the side effects are generally prohibitive.[155] Moreover, in low Earth orbit the risk of significant damage is low. Therefore, the focus of this research interest appears to be on future interplanetary missions. In addition to pharmaceutical countermeasures, the Soviets have been exploring methods of shielding (including the use of electric or magnetic fields around the spacecraft), personal dosimetry, and changes in flight profile as ways to protect against radiation.[156] [157]

### *Diet and Nutrition*

Soviet specialists believe that both a regular meal schedule and a carefully selected diet are important for the maintenance of overall conditioning and health in space. Nutrition is thought to have a synergistic effect with other countermeasures on the control of adaptive changes such as musculoskeletal strength/mass losses. However, the effect is difficult to measure, and experimental protocols are difficult to administer. It has been observed that cosmonauts can actually gain weight in space if exercise is combined with vitamins, calcium supplements, appealing foods, and appetite stimulators such as onions, garlic, and spices.[158]

Much effort has been devoted to determining the optimum diet in space. Cosmonauts are provided with a well-rounded diet (some of it supplied "on order" according to personal taste) including fresh fruits, vegetable, and condiments. They eat four meals per day, spaced 4–5 hours apart. The caloric value of the diet on the later Salyut missions averaged 3200 kcal—higher than on most U.S. missions.[159] Increased exercise regimens necessitated an increase in calorie content to maintain proper energy balance.[160] Because Soviet scientists believe that intake of vitamins, amino acids, and minerals promotes the retention of fluids and electrolytes, these substances have been administered in larger doses just prior to reentry.[161] It has been shown that proper dietary combinations can also help to regulate the digestion, offsetting enzymatic changes associated with the stresses of space flight.[162]

### *Psychological Support*

Distinct from the physiological countermeasures is the very extensive program of psychological support extended to cosmonauts on long-term missions. The emphasis on this area is much stronger in the Soviet program than in the U.S. program—perhaps largely because of the difference in mission durations.[163] There is an extensive Soviet research activity in "space psychology" focused not only on cosmonaut selection and training, but also on organization of the cosmonaut's daily routine (work/rest cycles, relaxation activities, etc.) and on aspects of mission support.

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[155] See for example Grigor'yeva, Ye.V., et al. The Effect of Radioprotective Agents on the Epithelium of the Mucous Membrane of the Small Intestine of Irradiated Animals. Radiobiologiya, 26(3), 1986, pp. 408–410.

[156] Kovalev, Ye. Ye., et al. Possible Directions of Refining Criteria of Radiation Safety of Space Flights. Kosmicheskaya Biol. i Aviak. Medit., 17(2), 1983, pp. 8–14.

[157] Ryabova, T. Ya. Electrostatic Shielding Against Cosmic Radiation (Current Status and Prospects). Kosmicheskaya Biol. i Aviak. Medit., 17(2), 1983, pp. 4–7.

[158] U.S. Congress. Soviet Space Program: 1976–80, op. cit., p. 700.

[159] Ibid.

[160] Bychkov, V.P., et al. The Biological Value of the Protein Included in the Rations of the Crews of the "Salyut" Orbital Stations. Kosmicheskaya Biol. i Aviak. Medit., 20(4), 1986, pp. 44–48.

[161] Yegorov, A. D. Results of Medical Research During the 175-day Flight of the Third Prime Crew on the Salyut 6-Soyuz Orbital Complex (NASA TM-76450). Washington, NASA, 1981.

[162] Smirnov, K. V., et al. State of Digestive System Following Long-term Space Flights. Kosmicheskaya Biol. i Aviak. Medit., 16(2), 1982, pp. 19–22.

Psychological support is organized and provided by a Psychological Support Group. The kinds of support are many and various. They include: [164] [165]

Television exchanges with family members, scientific specialists, and Soviet celebrities and viewing special events (such as sports)

Letters and mementos from home

Visiting crews

Movies, videotapes, news broadcasts, and music cassettes provided on request

Variations in work routine and diet

This program of psychological support has been found to be very effective in maintaining motivation and emotional stability in the crew. For example, the good humor of the crew of the 237-day Soyuz T-10/T-11 mission was credited to the psychological support they received.[166] The psychological support group also observes the crew via television and, if necessary, will suggest changes (e.g., in work schedule) to improve the psychological climate. Thus, this program is on a par with the program of physical countermeasures.[167]

### *Conclusion*

The Soviet program of physical countermeasures is said to have been built on that developed in the U.S. Skylab program.[168] It differs in some key aspects from that program—especially in the specific emphases of pharmacology and radioprotection and, to some extent, in the rigor of the exercise regimen. The Soviet program is tailored to the long-duration missions in low Earth orbit that have now become the norm, and it is effective in that milieu. The question is whether those countermeasures will be sufficient for even longer- term missions beyond the protective magnetic field and the relative nearness of Earth, e.g., to a lunar base or to Mars. To an important extent, this is the question that the Soviets are now striving to answer.

## SIMULATIONS OF GRAVITY AND MICROGRAVITY

Simulation of gravitational/acceleration forces and simulations of microgravity and some of its effects play an important role in

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[163] Myasnikov, V.L. Mental Status and Work Capacity of Salyut-6 Station Crew Members. Kosmicheskaya Biol. i Aviak. Medit., 17(6), 1983, pp. 22-25.

[164] Gazenko, O. G. Cosmic Biology and Medicine, Yesterday and Today, op cit.

[165] Blagov, V. D. Deputy Flight Director Blagov on 211-day Flight of Berezevoy and Lebedev. Zemlya i Vselennaya, no. 5, September-October 1983.

[166] Science in the USSR (G.K. Skryabin, Ed.). USSR Academy of Sciences, January/February 1985 (ISSN 0203-4638).

[167] Grigoriev, A. I., et al. Selected Problems of Psychological Support of Prolonged Space Flights. Institute of Biomedical Problems, Moscow, USSR, 1984.

[168] Sulzman, F. NASA Life Sciences Division. Personal communication, October 26, 1987.

Soviet space medicine and biology. Such simulations have four distinct purposes: training of cosmonauts, scientific research, design of mission protocols, and provision of countermeasures to microgravity. The first three involve ground-based simulation of microgravity conditions (with one exception—i.e., there is some training in high-gravity conditions on the ground). The fourth purpose, countermeasures, involves simulation of gravitational force in space. It should be emphasized that these four uses of simulation are distinct from the *simulators* used for training in the operational aspects of controlling specific space hardware systems.[169]

The most extensive use occurs in training. Primarily this is vestibular training in which trainees are subjected to rotational accelerations and simulated microgravity conditions using slowly rotating chairs, swings, and parabolic flight along a Keplerian trajectory.[170] Another important training function is rehearsal for space operations such as EVA *combined with* familiarization with spaceflight conditions. In the case of EVA, a special water immersion facility called the Hydrolaboratory (located at the Gagarin Cosmonaut Training Center) is used. Spacecraft simulators are suspended in this microgravity-simulation facility to provide operational training.[171] Another space-environment training facility is the hypobaric (low pressure) chamber, which is a hermetically sealed room in which rapid decompression and low atmospheric pressure conditions can be created for training purposes.[172]

A centrifuge is used to accustom cosmonauts to functioning under high acceleration loads such as those encountered during launch and reentry. The centrifuge used for cosmonaut training has an arm length of 18 m and can produce loads of up to 30 g's, with a rotational capability for simulating tumble. Cosmonauts have been exposed to transverse g-forces of up to 10 g's during training. High-G acceleration training has been shown to be effective in enhancing the tolerance to acceleration.[173]

The Hydrolaboratory is an especially effective simulator of spaceflight conditions, as it not only simulates microgravity conditions, but also requires an artificial atmosphere and special equipment, and produces the high emotional loads associated with EVA.[174] However, no terrestrial simulation of microgravity is completely realistic. For that reason, research on biomedical responses to microgravity using these and other ground-based simulations (bedrest in humans, hypodynamia and denervation of animals) has tended to produce inconclusive results. For example, the extensive research on space motion sickness has not yet yielded major breakthroughs in either the selection or the treatment of cosmonauts with respect to this problem.[175]

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[169] Garshnek, V. and R. Overmeyer. Preparing Cosmonauts for Space Flight: Simulation Facilities of the Soviet Space Program. In Proceedings of the Aerotech '87 Conference, Long Beach, CA, October 1987, Society of Automotive Engineers (in press).

[170] Barchukov, I. Leonov on Cosmonaut Training, op. cit.

[171] Shatalov, V. The Training of Cosmonauts. In History of the USSR: New Research (Vol. 5). Moscow, Nauka Press, 1986.

[172] Garshnek, V. and R. Overmeyer. Preparing Cosmonauts for Space Flight: Simulation Facilities of the Soviet Space Program, op. cit.

[173] Ibid.

[174] Ibid.

[175] Galle, R. R, et al. Simulation of Space Form of Motion Sickness. Kosmicheskaya Biol. i Aviat. Medit., 17(3), 1983, pp. 74–78.

Artificial gravity in space is a subject of some interest to American space program planners. There are two aspects here: research and operations. The use of artificial gravity aboard Soviet spacecraft for research on plants and animals is well established. Experiments on both biosatellites and orbital stations in which rats are maintained in a slowly rotating centrifuge, and in which plants are grown on a comparable device known as a clinostat, are a mainstay of Soviet space life sciences research.[176] The results of such studies are often reported in English in the proceedings of the Commission on Gravitational Physiology, of the International Union of Physiological Sciences. (See later section on "Space Biology.") Findings in recent years have shown that centrifugation in space is an effective general countermeasure to the adverse effects of prolonged microgravity, reducing bone demineralization, cardiovascular deconditioning, diuresis, and biochemical changes.[177]

These findings have helped to stimulate interest in the concept of large-scale artificial gravity applied to space stations as a countermeasure against the effects of microgravity in humans. Concepts range from a small onboard centrifuge to rotation of the entire station (e.g., with a toric design or using tethers). The benefits of the former are probably small, in comparison to the cost and technical problems involved (i.e., power consumption, torque forces), and in comparison to the proven benefits of existing, much simpler measures such as LBNP. There are serious problems associated with rotating stations. Gravitational force vectors would change continuously depending on distance from the center and axis of rotation, requiring adjustment on the part of inhabitants. Furthermore, there is some concern that head movements in such an environment might create coriolis reactions due to angular acceleration, destabilizing the vestibular system. Therefore, many space medicine specialists are not yet convinced that this approach is practicable.[178]

## ISOLATION AND CREW INTERACTION

The emphasis on long-duration space flight in the Soviet space program has led them to a longstanding interest in the psychology and sociology of social isolation and crew (small group) interaction. The great emphasis they place (relative to the U.S. program) on psychology and crew compatibility is ultimately focused on ensuring "support of high levels of job performance by the crew during all stages of flight." [179] As Cosmonaut Georgiy Grechko has said: "The success of any flight largely depends on the psychological microclimate among the crew. If conflicts arise in orbit, there can be no really intensive work." [180]

Much Soviet research on isolation has involved prolonged stays in polar regions, particularly Antarctica, where the long-term scientific missions offer a unique testbed or analog of space flight. Another analog is isolation chambers, which offer a more controlled experiment setting. These may involve any number of individuals, depending on the parameters being studied.

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[176] U.S. Congress. Soviet Space Programs: 1976-80, op. cit., pp. 717-718.

[177] Lanzerotti, L. J., et al. Soviet Space Science Research, op. cit., p. V-10.

[178] Berry, C.A. Physiological and Psychological Parameters of Life in Space Stations, op. cit.

[179] Grigoriev, A. I., et al. Means and Methods for Preventing the Undesirable Effects of Weightlessness, op. cit.

[180] Sovetskaya Rossiya, October 31, 1987, 3rd ed., p. 4.

Results include a detailed description of Wenterer's syndrome (cabin fever), which includes among its symptoms depression, hostility, irritability, sleep disorders, loss of interest in work, and diminished intellectual capacity.[181] Isolation can bring about neurotic reactions due to the lack of feedback and stimulation, general drowsiness and lethargy, sleep disorders, and psychological stress.[182] These symptoms—falling productivity, sleeplessness, anxiety and hostility, even murder—have all been seen in the Antarctic.[183]

Although the symptoms just described sound alarming, ordinarily cosmonaut training, the work program, and extensive psychological support prevent their full development. However, there have been problems. On a 96-day mission to Salyut 6 in 1978, for example, Georgiy Grechko and Yuriy Romanenko had what Grechko calls a "black day" in which they had a serious altercation on some trivial point.[184] Aboard Salyut 6 for the 185-day mission in 1980, Valeriy Ryumin and Leonid Popov became extremely irritable and angry with each other and with the ground controllers for a considerable period of time.[185] Reportedly, the worst Soviet experience from this standpoint came in 1982, with the 211-day mission to Salyut 7. Some Western analysts believe that this mission was terminated early due to the growing inability of cosmonauts Berezovoy and Lebedev to get along.[186] Berezovoy later referred to "certain human-interrelationship questions . . . we were unable to resolve. . . ." [187]

An important point may be that made by Gen. Beregovoy, commander of the Cosmonaut Training Center. He has expressed the view that 30 days is the maximum time that crewmembers can get along easily; after that point, he says, "the crews begin to show signs of hostility, in spite of the diligent testing to arrange personality compatibility." [188] Grechko elsewhere makes the same point, saying that the compatibility factor emerges on flights lasting a month, and is essential on longer flights.[189] The recent report of a 1968 Soviet isolation-chamber experiment lasting a year also suggests that difficulties of interaction emerged at the 30-day point.[190]

Another consideration is the ideal size of long-term space crews. There have been concerns that a three-person crew pits two against one in the event of an argument, or allows one member to be ostracized.[191] Dr. Oleg Atkov commented, following the 237-day mission on which he participated in 1984, that the crew addressed this potential problem successfully by not involving the third crew member in such instances, but allowing him to work out a compromise.[192]

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[181] Terelak, J. Some Psychological Consequences of Prolonged Social Isolation. Kosmicheskaya Biol. i Aviak. Medit., 18(2), 1984, pp. 54–56.

[182] Leonov, A. A. Prospects for the Conquest of Space and Psychology. In Psychological Problems of Space Flights. Moscow, Nauka Press, 1979, pp. 35–40.

[183] Maugh, T. H., II. Cooped Up. Los Angeles Times, September 28, 1987, Pt. 2, Science/Medicine, p. 2.

[184] Sovetskaya Rossiya, op. cit.

[185] Maugh, T. H., II. Cooped Up, op. cit.

[186] Ducrocq, A. The Terrible Return. Air et Cosmos, December 18, 1982, pp. 52–63.

[187] Zubkov, V. I and My Comrade. Sotsialisticheskaya Industriya, December 26, 1982, p. 4.

[188] Quoted in: Bluth, B. J. Soviet Space Stress, op. cit.

[189] Conversation in the Editorial Office of Literary Gazette: Experience of Character. Excerpts from Literary Gazette, no. 1 (4755), January 1, 1980, pp. 12–13.

[190] Expedition: From the Diary of Andrey Bozhko, Subject in an Experiment to Test Space Technology. Sovetskaya Rossiya, August 8, 1986.

[191] Ibid.

There are many indications of the importance which is accorded to these concerns about social isolation and crew interaction in space. The addition of two sleeping compartments to the Mir space station is a concession to the need, frequently expressed by cosmonauts, to have a degree of privacy.[193] A researcher at the Institute of Biomedical Problems was quoted as saying that visiting crews to the orbital stations are carefully briefed on the status of the crew, so that their intrusion will be in tune with the onboard psychological "microclimate." [194] And the television monitoring by the Psychological Support Group is intended to give early warning of tensions of this type.

## EXTRAVEHICULAR ACTIVITY: BIOMEDICAL HIGHLIGHTS

The years 1984–87 were banner years for Soviet extravehicular activity. In particular, 1984 saw a total of seven EVAs carried out, all during the same prime crew mission to Salyut 7. Details of all the EVAs are presented in Chapters 2 and 3 of this report. This section will briefly highlight the aspects of EVA which are of biomedical significance.

Standing out is the record set by cosmonauts Kizim and Solovyev, who flew together on both the Soyuz T-10/T-11 and T-15 missions, in 1984 and 1986, respectively. They compiled a total of 31 hr 40 min of EVA time in eight separate activities. Six of the EVAs took place on the 237-day Soyuz T-10/T-11 mission, four of them within a 10-day period between April 24 and May 4, 1987. On two of their eight EVAs, Kizim and Solovyev remained outside the station for 5 hours, a new Soviet EVA duration record. Medical doctor Oleg Atkov, the third crewmember on the Soyuz T-10/T-11 mission, monitored the two cosmonauts continuously from inside the Salyut station throughout their EVAs. It is notable that on both missions the first EVA occurred some 75 days into the mission, demonstrating that the cosmonauts were judged to have ample strength and motor coordination, even at that point well into the flight, to accomplish their extensive EVA operations.

On July 25, 1984, Svetlana Savitskaya became the first woman to perform an EVA in space. Her 3.5-hr EVA to carry out welding and other experiments was routine in every respect. In the 1984–1987 time frame, EVA durations grew to an average of 3–4 hours.

The unscheduled, unplanned EVA accomplished by cosmonauts Romanenko and Laveikin on April 12, 1987, to assist in the docking of the Kvant module to Mir was a notable event. It demonstrated once again the versatility and ingenuity of humans in space missions, especially for dealing with contingency situations such as the docking problem presented.

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[192] Meditsinskaya Gazeta, April 12, 1985.

[193] Maugh, T. H., II. Cooped Up, op. cit.

[194] Lenorovitz, J. M. Soviets Expected to Consolidate Space Program Activities in 1987. Aviation Week and Space Technology, January 12, 1987, p. 97.

An improved EVA suit has been developed for use with the Mir station.[195] Derived directly from the EVA suit employed on the Salyut stations, it is said to contain modifications based on previous operational experience. The Soviet EVA suit is different from the American version in that it is entered through a large opening on the back, facilitating the donning of the suit. Visibility through the faceplate is said to be less than that on U.S. EVA suits. Also, the suit's gloves are said to be difficult to manipulate, and it is reported that cosmonauts in training for EVAs perform hand exercises to gain the strength needed for operations with the gloves.[196] Like the earlier design, the new EVA suit has an extensive capability for medical monitoring of the wearer's EKG, pulse, and respiratory rates by monitors on the ground.

In a related technology development, it was reported that a new module is being prepared for use with Mir. The module, described as similar in size to the Kvant astrophysics module now docked with the station, is said to be intended primarily for use as an EVA airlock. According to Gen. Shatalov, "The new module will act as an airlock to provide better facilities for EVA and to make the EVA easier and simpler.[197]

## LIFE SUPPORT SYSTEMS

Space is, of course, an extremely harsh environment characterized by extremes of temperature and lacking the atmosphere needed to sustain terrestrial life. Habitation in this environment requires a space capsule that contains the essentials needed to support life. The capsule must contain an appropriate amount and pressure of oxygen, a moderate temperature, necessary food and water, and the means to dispose of metabolic waste products such as carbon dioxide, urine, and feces. Systems that provide these requirements must function 24 hours per day. Facilities for personal hygiene, contamination control, illumination, and personal space, while not strictly essential for life, are nonetheless crucial for sustaining space crew morale and work productivity over prolonged stays in space. The engineering means by which such needs are met may be considered under the collective title of "life support systems." A comprehensive textbook on this subject for Soviet engineering students appeared in 1983.[198]

### *Metabolic Requirements in Space*

Soviet studies have determined that the average adult in space requires each day approximately 800 grams of oxygen, 700 grams of solid food with a total caloric value of 3000-3300 kcal, and 2500 grams of drinking water. If resulting bodily excretions are not recycled to produce oxygen, food, and water, then a three-person crew on a one-year mission would require 1.5 tons of food, 3.3 tons of bound oxygen, and 5.9 tons of water. This material would equal nearly half the total weight of a contemporary Soviet space station. It is therefore practical to meet as much as possible of these metabolic requirements through either resupply or regeneration by onboard systems.[199]

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[195] Soviets Studying Development of Emergency Capsules for Mir. Aviation Week and Space Technology, October 26, 1987, p. 75.

[196] Soviets Display Suits Similar to Those Used on Mir. Aviation Week and Space Technology, October 19, 1987, p. 112.

[197] Soviets Planning to Launch New Module to Mir Station. Aviation Week and Space Technology, October 12, 1987, p. 22.

[198] Serebryakov, V. N. Principles for Designing Life Support Systems for Crews of Space Flight Vehicles. Moscow, Mashinostroyeniye, 1983.

*Environmental Control Life Support System*

The Environmental Control Life Support System (ECLSS) used aboard Soviet orbital stations of recent vintage includes systems for atmospheric regeneration and circulation, water reclamation and supply, and power generation. (Although the latter system provides the power needed to operate most other onboard systems, it is not specifically of biomedical interest, and will not be dealt with here.) ECLSS systems aboard the third-generation Mir station are the same in most respects as those used aboard the Salyut series of stations. But there are some key differences, which will be noted. In addition, greater automation of functions aboard the Mir station will relieve the crew of some of the burden of operating the life support systems.

*Atmospheric Regeneration and Circulation*

On average a cosmonaut consumes about 25 liters of oxygen and releases 20 liters of carbon dioxide per day. Onboard air is also lost whenever an airlock is opened. On Mir, an effort is made to maintain an atmospheric pressure of 800-970 mm Hg.[200] This is slightly higher than the pressure used aboard Salyut 6 (760-960 mm Hg). Oxygen partial pressure aboard Salyut 6 was 160-280 mm Hg; carbon dioxide pressure was 1.23-9.00 mm Hg; water vapor partial pressure was 7.0-16.4 mm Hg. The remaining gas pressure was and is supplied by inert nitrogen. Air temperature was maintained in a range of 19.0-24.5° C (66.2-76.1° F).[201] Table 14 gives the values of these parameters in different situations aboard Salyut 7. Note the increases in humidity and carbon dioxide when a visiting crew was aboard; the systems must be designed to handle this additional load.

TABLE 14.—MEAN VALUES OF MICROCLIMATE PARAMETERS DURING PERFORMANCE OF SOME OPERATIONS ABOARD THE SALYUT 7 STATION

| Operation | Air temperature |  | Air humidity (percent) | Gas composition of atmosphere, MM HG |  |
|---|---|---|---|---|---|
|  | (°C) | Range |  | $O_2$ | $CO_2$ |
| Technological experiments | 23.9 | 23.0–25.6 | 40–60 | 160–188 | 1.76–5.60 |
| Television broadcasts | 23.3 | 22.0–24.7 | 40–70 | 159–198 | 1.20–5.90 |
| Visit by rendezvous crew | 23.7 | 23.0–25.5 | 50–60 | 156–183 | 3.7–5.7 |
| Overall mean during first prime mission | 21.8 | 17.0–25.6 | 40–80 | 152–200 | 0.5–6.0 |

Source: Bluth, B.J. and M. Helppie. Soviet Space Stations as Analogs (2nd ed.). Washington, NASA, August 1986, p. I–92. Reprinted with permission.

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[199] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 703.

[200] Semenov, Yu. The Beginning of the MIR Station Active Operation. Presented at the 38th Congress of the International Astronautical Federation, Brighton, UK, October 10–17, 1987, IAF–87–84.

[201] Semenov, Yu. and L. Gorshkov. "Salyut-6" Orbital Station: Home, Laboratory, Vehicle. Nauka i Zhizn, no. 4, April 1981, pp. 44–53, 125.

On the Salyut stations, oxygen was regenerated from carbon dioxide and water by chemical oxygen regenerators, using oxides and superoxides of alkali metals (e.g., potassium) as an oxygen source. This chemical generation system had the advantages, compared to liquid oxygen as used on the U.S. Skylab, of reduced weight, less flammability, and greater simplicity. The disadvantage of this system was that it was not as flexible in altering the gaseous environment rapidly, when needed.[202] It also required the delivery to Salyut of the nonreusable chemical cartridges containing the regenerator.

Aboard Mir, a new system is used to generate oxygen. This "Electron" system uses chemical electrolysis to decompose water into oxygen and hydrogen.[203] This system has the advantage of decreasing resupply traffic, since water can be delivered to the station more conveniently and is stored in greater reserve.

The system for removing carbon dioxide is also new on Mir. Aboard Salyut, lithium hydroxide was used as a scrubber, producing lithium carbonate and water.[204] The scrubber was contained in reusable cartridges. This system has been replaced with a "Vozdukh" system which is said to "absorb and remove carbon dioxide directly into space."[205] Technical details are unknown at this time, although it is known that the Soviets had been experimenting with molecular sieves, synthetic zeolites, and supercooling as possible ways to remove carbon dioxide from the atmosphere.[206]

Fans pull the air through the regenerators and scrubbers, and distribute it throughout the station at a flow rate of 0.1–0.8 m/s, depending on location (Salyut 6).[207] Investigations of air flow aboard Salyut 7 showed that the distribution was highly uneven across zones, and ventilation was especially poor in the sleeping areas.[208] A U.S. aerospace news magazine reported that on the Soyuz T–9 mission in late 1983, an acrid odor that irritated the crew was attributed to a problem in the ECLSS.[209] Presumably, changes in Mir systems and interior layout took any such problems into account.

### *Water Reclamation and Supply*

Water is consumed by humans in the form of liquid water and food, and is excreted in bodily wastes, perspiration, and exhaled water vapor. Spacecraft designers must decide whether to collect and store the excreted water, jettison it into space, or recycle it for subsequent consumption (or some combination of these). Earlier Soviet space vehicles, in space for only brief durations, brought their water supply from Earth and stored the waste products for subsequent return to Earth. The Salyut series of longer-duration vehicles has employed systems to recycle much of the liquid waste for subsequent use by the crew. These systems appear to be essentially unchanged on the Mir station.

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[202] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., pp. 705–706.

[203] Semenov, The Beginning of the MIR Station Active Operation, op. cit.

[204] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 706.

[205] Semenov, Yu. The Beginning of the MIR Station Active Operation, op. cit.

[206] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 704.

[207] Semenov, Yu. and L. Gorshkov. Feature Article on "Salyut-6" Design and Subsystems, op. cit.

[208] Zaloguyev, S.N., et al. Sanitary and Hygienic Features of Cabin Environment in Salyut-7 Orbital Station, op. cit., pp. 52–57.

[209] Covault, C. Explosion, Leak Cripples Salyut-7 Effort. Aviation Week and Space Technology, October 10, 1983, pp. 23–26.

Every 24 hours, a person releases 1.5–2.0 kg of water vapor through breathing and perspiration. This water vapor is recycled aboard Soviet stations by condensing it on cooling coils in an "atmospheric moisture regeneration system". The condensate, as well as water previously used for bathing, is passed through ion exchange columns and then through activated charcoal filters prior to being sterilized by heating. Minerals such as calcium, magnesium, bicarbonate, chloride, and sulfate are added to this recycled water, which is then stored in water batching units for future use. Fresh water is brought to the spacecraft from Earth by the Progress resupply ship. This water is sterilized by ionic silver, an effective sterilizing agent.[210]

The atmospheric moisture regeneration system produces about 0.85 liters of water per person per day, depending on the intensity of physical exercise and resulting perspiration rates. Reportedly, about 50 percent of the water on Salyut 6 was recycled by these means.[211] The use of this system was said to have reduced the weight of storables from 10.7 tons to 2 tons.[212] According to some Western analysts, urine is also recycled. Dr. B. J. Bluth, of NASA, reports being told by a cosmonaut in 1985 that such a system was in place on Salyut 7, but crew members preferred not to drink the recycled urine water, so it was stored separately as a backup water source.[213] However, in September 1985, the Soviets publicly stated that they were recycling only from atmospheric water condensate, not urine. They did note that "in the near future there'll be new systems which will recycle other products of the human metabolism." [214]

### *Essential Facilities*

Beyond the basics of air and water, facilities for food service, waste management, and personal hygiene are essential elements of onboard life support.

#### *Food Service*

Packaging, storage, and preparation of food in microgravity presents a set of problems that have drawn considerable attention since the beginning of the Soviet space program. The nutritional content of the space diet is viewed as medically important, and was discussed under "Other Countermeasures"; the systems for delivering this countermeasure are described here.

The availability of rehydrated foods has greatly increased the diversity of foods available to Soviet space crews. Beginning with Soyuz 9, in 1970, cosmonauts had both hot and cold water available aboard the spacecraft. As the available water supply increased on the Salyut stations, due to the implementation of water recycling methods and regular resupply from Earth, the types and quality of foods expanded. Later Salyut crews have had dehydrated, canned, and fresh foods, and foods packaged in tubes.

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[210] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 707.

[211] Oberg, J.E. Made in the USSR: KOSMOGRAD Space Colony Number One? Space World, April 1981, pp. 4–13.

[212] Adamovich, B. A. Life Support in Zemlya i Vselennaya, No. 6, November-December 1980, pp. 20–25.

[213] Bluth, B.J. Report on IAF Congress in Stockholm, Sweden, October 1985.

[214] Moscow World Service, 0831 GMT, September 23, 1985.

The Mir station, like the Salyuts before it, is equipped with a dining table, two ovens for heating food, hot and cold water dispensers, a refrigerator, storage containers, eating implements, a food rehydrator, and means for cleaning and sanitizing utensils and disposing of leftovers.[215] [216] In Mir, the dining table is in the area of the working compartment referred to as the "saloon". Fold-down leaves of the table contain panels for securing food in microgravity; inside the table is an electric food heater.[217] Cosmonauts on the 237-day mission in 1984 commented that the food aboard space vehicles was gradually approaching the kind and quality of food they eat on Earth.[218]

### *Waste Management*

Solid wastes (feces) are collected in hermetically sealed metal or plastic containers. Roughly once a week, the containers are ejected from the station through an airlock.[219] (This practice is still followed on Mir.) Other solid waste, including trash and some food wastes, is stowed in the expendable Progress cargo vehicles, which are incinerated upon reentry into the Earth's upper atmosphere.[220]

The toilet unit is located in a lavatory/washroom area isolated from the rest of the working module, near the aft docking port. The urine collector is a separate, cup-and-tube device with a disposable plastic insert and filter.[221] Soviet space life scientists told their U.S. counterparts that a female cosmonaut, Svetlana Savitskaya, had no difficulty in using these facilities aboard Salyut 7.[222]

### *Personal Hygiene*

In view of the confined living quarters aboard a space station, personal and communal hygiene must be given serious attention. Not only is it important for crew members to be comfortable if they are to remain motivated; it is also essential to reduce the risk of transmission of pathogenic organisms among the crew. Recognizing the importance of these matters, Dr. Atkov, on the 237-day Salyut 7 mission in 1984, made a series of studies to determine whether the personal hygiene facilities were effective.[223]

In the Mir station, a lavatory and washing device are located near the hatch connecting the working module with the intermediate chamber.[224] An electric razor is located in each of two small cosmonaut cabins that are new features of Mir.[225] Dental prophylaxis is accomplished using an electric toothbrush (with non-foaming toothpaste) as well as different approaches to dental massage.[226] Cleaning of the skin is accomplished by means of antibacterial towels. The towels are impregnated with a disinfectant, and are moistened before use.[227]

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[215] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 700.

[216] Semenov, Yu. The Beginning of the MIR Station Active Operation, op. cit.

[217] Pochkayev, I., et al. The "Mir" Space Station. Aviatsiya i Kosmonavtica, November 1986, pp. 22–23.

[218] Moscow World Service, 2100 GMT, July 22, 1984.

[219] Lebedev, V. Excerpts From Cosmonaut Lebedev's Flight Diary. Pravda, August 15, 1983, p. 7.

[220] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 708.

[221] Sudakov, V. Cosmonaut Ivanchenkov Interviewed on Living Conditions Aboard Salyut Station (June 1984). In (J.W. McBarron, II, compiler) Soviet EVA Operations and Equipment Data, NASA Johnson Space Center, January 28, 1985.

[222] Soffen, G.A. and A.E. Nicogossian. NASA internal memorandum, March 3, 1983.

[223] Izvestiya, February 18, 1984.

[224] Semenov, Yu. The Beginning of the MIR Station Active Operation, op. cit.

Based on a model displayed at the Paris Air Show in 1987, the shower device in Mir appears to be the same as that on the Salyuts.[228] Mounted on the ceiling of the main compartment, the Salyut shower consisted of a collapsible elastic cylinder (the shower booth) with two end caps that contained the necessary hardware. Nozzles at the top mixed and sprayed hot and cold water downward. Warm air was pumped downward toward the bottom cap, where it was drawn with the water through holes into the waste container. Rubber slippers were attached to the floor to hold the user in place while showering. Using this shower, the cosmonaut breathes through a snorkel-like tube that leads outside the shower booth. Towels are used to dry the body and the interior walls of the booth. When all cosmonauts are finished showering, the shower is raised accordion-fashion back to its storage place on the ceiling.[229]

In Salyut 6 and 7, cosmonauts typically showered about once every 10 days, and occasionally as seldom as once per month. Because it was a complicated procedure, most of a day was required for all the crew to shower. However, the showers themselves each took only about 15 minutes.[230]

It may be noted that one Western source reported that there is no shower on Mir.[231] According to this account, the washing facility consists of a shower head inside an enclosure into which the cosmonauts insert their head and hands.

### *Cabin Environment*

Aspects of the cabin environment such as air quality, microorganism population, design, and decor are important not only for crew comfort but also to ensure their health and productivity.

#### *Contamination Control*

An inherent problem in a sealed environment such as a spacecraft is that resident humans contaminate the environment through the emission of volatile mixtures of gases and particulates generated from exhaled air, perspiration, urine, and intestinal gases. Some 400 such products have been identified—20 of them in more than trace amounts, consisting of amines, aldehydes, ketones, acids, alcohols, and polycarbonates.[232] Not only are these materials noxious to breathe; in sufficient concentrations they could be toxic.

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[225] Soviets Exhibit Full-scale Model of Mir Complex at Paris Air Show. Aviation Week and Space Technology, July 20, 1987, p. 58.

[226] Lebedev, V. Excerpts From Cosmonaut Lebedev's Flight Diary, op. cit.

[227] Ibid.

[228] Soviets Exhibit Full-scale Model of Mir Complex at Paris Air Show, op. cit.

[229] Feoktistov, K. P. and M. M. Markov. Evolution of 'Salyut' Orbital Stations. Zemlya i Vselennaya, no. 5, September-October 1981, pp. 10-17.

[230] Sudakov, V. Cosmonaut Ivanchenkov Interviewed on Living Conditions. Aboard Salyut Station, op. cit.

[231] Furniss, T. Inside Mir. Space World. May 1987, pp. 24-25.

The rate at which the human body releases these chemicals into the environment depends upon the degree of motor activity, the nature of the atmosphere, and diet.[233] In addition to human-generated chemical contamination, onboard instruments and equipment typically is a source of atmospheric contamination through offgassing. However, this may not be a problem on Mir. Cosmonaut Romanenko has been quoted as saying that, ". . . all the instruments provide for good fresh air. It's much better than Salyut." [234]

Biological contamination also occurs, due to the presence of humans. The main types of microorganisms present are staphylococci, other bacteria, and gram-positive spore bacilli. Primarily these microflora are non-pathogenic bacterial types. They are carried in aerosols in the air, and are found on most spacecraft internal surfaces. The aerosols are ubiquitous; a clothed person emits 100 thousand to 30 million aerosol particles per minute, depending on physical activity.[235]

The Soviets employ a series of filtering media for the removal of waste gases and microparticulates. These include activated charcoal filters, high-efficiency fiberglass filter, and catalytic chemical absorbents.[236] Most of the microorganisms present are sensitive to antibiotics, so disinfectant solutions are used in frequent cleaning. Such measures aboard Salyut 6 reportedly kept bacterial contamination at less than 400 microcells per cubic meter air, and at about 250 + 100 microcells per 100 cm3 of surfaces.[237]

### *Habitable Space*

Total volume of the core module of Mir is about 90 m3, roughly the same as in Salyut.[238] The habitable volume is somewhat less than that. However, the new station is decidedly more spacious than its predecessors because of several innovations. The primary change is that most equipment and instruments have been removed. They will be contained instead in the modules, such as Kvant, that are to be docked to Mir. Off the central compartment of the station are two "staterooms". Although not large, these quarters are intended to provide private areas in which cosmonauts can relax or attend to personal tasks.[239] Each contains a sleeping bag, desk, armchair, stowage bins, and porthole.

Even with these improvements in livable space, the available volume is not large considering that a prime crew size of 5–6 is planned.[240] However, each of the planned modules will contain its own habitable space, so that the effective habitable volume of the modular complex will increased "several times." [241] Kvant itself added 40 m3 to the habitable volume of the complex.

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[232] Nefyodov, Yu.G. and Zaloguev, S.N. Environmental Aspects of Habitability of Manned Spacecraft. Presented at 32nd Congress of the International Astronautical Federation, Rome, Italy, September 6–12, 1981.

[233] Ibid.

[234] Surging Ahead. Time, October 5, 1987, p. 64.

[235] Nefyodov, op. cit.

[236] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 704.

[237] Yegorov, A.D. Results of Medical Studies During Long-term Manned Flights on the Orbital Complex Salyut-6 and Soyuz, op. cit.

[238] Semenov, Yu. The Beginning of the MIR Station Active Operation, op. cit.

[239] Semenov, Yu and V. P. Legostayev. Some Aspects of the Salyut -7/Mir Station Operations. Presented at the 37th Congress of the International Astronautical Federation, Innsbruck, Austria, October 4 -11, 1986. IAF-86-41.

[240] Semenov, Yu. The Beginning of the MIR Station Active Operation, op. cit.

### *Decor*

Throughout their Salyut program the Soviets experimented with interior colors in an effort to:[242]

provide a "homey" quality
provide psychophysiological stimulation
give a sense of floor/ceiling orientation

In Salyut 6, soft pastels were used. Salyut 7 was painted in brighter colors: green and beige walls, with a white ceiling.[243] In Mir, the walls of the living area are painted yellow, with an off-white or light gray ceiling and tan carpet. The walls of the crew compartments are light green, as is the forward compartment of the station.[244] The addition of carpeting throughout the station increases the sense of normal home/office space, while perhaps dampening vibration and sound. Such considerations of interior design are thought to be important in long-duration missions, and are given serious attention by psychologists and human factors engineers.[245]

### *Future Direction in Life Support*

The primary thrust at present in the area of life support is toward the development of partly or fully closed biological life support systems. Such onboard systems would use biologically generated waste products onboard (solid and liquid wastes as well as exhaled carbon dioxide) as inputs, with the outputs being purified water, oxygen, and food. Thus, they would replace or assist current regeneration systems and food provisions. Such systems are thought to be essential for long-duration interplanetary missions, in which there are constraints on overall vehicle weight and resupply is not possible. Bioregenerable technology is discussed at greater length under the heading "Space Biology."

## CREW PROTECTION AND SAFETY

All the biomedical measures and countermeasures discussed in previous sections of this chapter are directed, in a sense, at crew protection and safety. Indeed, the spacecraft itself is essentially a protective shell, as is the space suit worn in EVA and other operations. In this section, the discussion of protection and safety focuses on specific technological and procedural interventions designed for contingency or emergency situations in space.

Such emergency situations can encompass the following:[246]

a meteorite impact causing decompression of the spacecraft cabin

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[241] Ibid.

[242] Gurovskiy, F. P. et al. Designing the Working and Living Conditions of Cosmonauts. Moscow, Mashinostroyeniye Press, 1985.

[243] Konovalov, B. A Trip Through the Salyut 7. Ivestiya, May 18, 1982, p. 3.

[244] Soviets Exhibit Full-scale Model of Mir Complex at Paris Air Show, op. cit.

[245] Gurovskiy, F. P., et al. Designing the Working and Living Conditions of Cosmonauts, op. cit.

[246] Severin, G.I., et al. Crewman Rescue Equipment in Manned Space Missions: Aspects of Application. Presented at the 38th Congress of the International Astronautical Federation, Brighton, UK, October 10 -17, 1987 (IAA-87-576).

an increase in radiation due to solar flares
failure of key life support system(s)
smoke and/or fire aboard the spacecraft
emergency transfer of crew to another space vehicle

There are a variety of options available to a Soviet crew faced with one of these emergencies in space. In the event of a problem with the space station (decompression, life support failure, or fire/smoke), the crew would normally abandon the station and enter the Soyuz transport ship. They can then either remain in the Soyuz for several days, if appropriate, orbiting separately or attached to the station, or return to Earth. (Emergency landing procedures include an ocean splashdown or a landing in one of many reserve areas.) In the event of a power failure, the Soyuz descent module serves as an emergency return vehicle. This return option can also be used if a large flux of solar-flare or other radiation occurs.[247]

Each Soyuz vehicle is equipped with survival suits—lightweight, easily donned suits that are individually tailored to each cosmonaut, and that can operate either off the Soyuz life support system, off a separate cabin supply of air, or of a self-contained backpack system. This suit is donned in most emergency situations in which the Soyuz is used as a safe haven. The survival suit provides good protection against all of the above emergencies except radiation.[248]

Apart from these in-space dangers, there is also the danger of a launch abort requiring emergency removal of the crew from the area. Such a situation did occur on September 26, 1983, when a rocket caught fire during an attempt to launch a Soyuz mission to Salyut 7. The Soyuz T emergency escape rocket system was activated moments before the launch vehicle exploded, and carried the crew safely several kilometers downrange. General Shatalov later reported that the crew experienced 15-17 g's during the abort.[249] [250] (This launch attempt is referred to as Soyuz T-10A.)

Western sources claim that the Soyuz has been used at least twice before as a safe haven in an apparent emergency. The most recent event reportedly took place when, on Soyuz T-9 in 1983 (the prime mission that was in orbit when the Soyuz T-10A launch abort occurred), nitrogen tetroxide leaked from the Salyut's main propulsion system. It was reported in the West that the crew sealed themselves in their Soyuz ferry craft, wearing their survival suits, until it was determined that the mission could continue. (The toxic fuel was said to have leaked into space, not into the spacecraft cabin.) [251]

Although the probability of a strike by a micrometeorite large enough to penetrate the external wall of a Soviet station is said to be extremely low, strikes by small particles are common. It has been calculated that such stations are struck by 1-2 small micrometeorites on each revolution, on average.[252] These particles merely erode the station surface very slightly. Nevertheless, there are pressurization monitoring devices onboard to warn of pressure loss; and there are established procedures for evacuating the station in the event of a rapid decompression. Other safety devices onboard the Soviet stations include a fire detection system, fire extinguishers, and radiation monitors.[253]

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[247] Vasilyev, A. Space and Detente. Soviet Life, April 1981, pp. 4-5.

[248] Severin, G.I., et al. Crewman Rescue Equipment in Manned Space Missions: Aspects of Application, op. cit.

[249] U.S. Congress. Soviet Space Programs 1976-1980, Pt. 2, op. cit.

[250] Konovalov, B. Man and Space: Why the Route to the Stars is a Thorny One. Nedelya, no. 41, October 12-18, 1987, pp. 7-9.

[251] O'Toole, T. Cosmonauts Land Safely After Imperiled Mission. Washington Post, November 24, 1983.

Training to cope with emergency situations is conducted inflight as well as on the ground. Exposure to realistic, stress-producing emergency situations is emphasized. One simulated emergency evacuation of the Mir was carried out in 1987 by the Soyuz TM-2/TM-3 crew. The simulation was terminated just before separation from the Mir.[254]

Improvements in Soviet crew protective systems are continually being made. For example, the Soyuz survival suit has been improved for use in the Soyuz T/TM craft. The new suit is said to permit greater mobility. It operates in two pressure modes, with standard and "back-up" pressures.[255] It has been reported that the Soviets are also studying the development of small emergency capsules which could be used for crew escape from Mir.[256] In addition, the Soyuz TM vehicle has larger reserves of air in its life support system, enough for descent in the event of a failure of the oxygen supply system.[257]

The Soviets have also expressed interest in establishing international standards for life support systems, interfaces, and connectors of space suits, capsules, and other safety-related equipment. The idea of an international "space rescue service" has recently been presented.[258]

## SPACE MEDICINE

A distinction can be made between space medicine, construed as research and other medical activities involving humans, and space biology, which refers to research involving animals, plants, insects, cells, and all other non-human life forms. (This is more an American than a Soviet distinction, but it is a useful organizing principle.) Soviet space biological research is pursued largely in support of the space medicine work on human subjects. Both forms of activity are conducted not only in space, but also on the ground; indeed, the amount of ground-based research far exceeds that conducted in space, even given the relatively large amount of access to space that Soviet life scientists enjoy.

Ground-based research in Soviet space medicine includes studies carried out not only in the conventional clinical laboratory setting, but also in environments that simulate aspects of the spaceflight environment: at high mountain altitudes, under water, in polar regions, in jet aircraft, etc. The laboratory studies themselves include a wide range of techniques for simulating weightlessness and other space factors. Some of the most commonly used simulation techniques are:

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[252] Koptev, Yu. Hologram Experiments in Space. July 19, 1981, p. 2.

[253] Feoktistov, K. P. and M. M. Markov. Evolution of "Salyut" Orbital Stations, op. cit.

[254] Moscow World Service, 0700 GMT, August 31, 1987.

[255] Severin, G.I., et al. Crewman Rescue Equipment in Manned Space Missions: Aspects of Application, op. cit.

[256] Soviets Studying Development of Emergency Capsules for Mir. Aviation Week and Space Technology, October 26, 1987, p. 75.

[257] TASS, 1744 GMT, May 23, 1986.

[258] Severin, G. I., et al. Crewman Rescue Equipment in Manned Space Missions: Aspects of Application, op. cit.

hypo- and hyperkinesia (i.e., reduced and exaggerated activity), with extended bedrest as the most common means of inducing hypokinesia

head-down tilting to various degrees of inclination

hypo- and hyperbaric studies (low and high atmospheric pressure)

hypoxia and hyperoxia (low and high oxygen concentration in air)

hypo- and hypercapnia (low and high carbon dioxide concentration in air).

The space-based studies take place aboard Soviet spacecraft, particularly the orbital stations (with preflight and postflight measurements often being made on the ground for comparison purposes). Cosmonauts are extensively monitored from the ground by space medicine specialists. They may also monitor themselves and each other; furthermore, two cosmonauts on missions to date (in 1964 and 1984) have been physicians. Visiting crews are typically used to study the acute phase of adaptation to space, while prime crews are used as subjects for more long-term studies. Visiting crews also serve as control subjects, and as couriers for the return of medical samples.

It may also be useful to distinguish between "biomedical research" and "operational medicine". The first is basic research on the physiological processes occurring in various specific body systems, with respect to actual and simulated spaceflight factors. The latter is actual medical support provided to cosmonauts pre-, in-, and postflight. It involves technology and procedures development as well as research. Both categories of space medicine will be discussed in this section.

Much of the salient information relating to space medicine from a more programmatic and cross-cutting point of view was presented in the previous section, "Topics of Special Interest"—especially in those subsections dealing with adaptation and countermeasures to space flight. Here, the focus is on specialized areas of research in which the total Soviet research effort is quite extensive. Therefore, the approach is to attempt briefly to describe the most important findings reported in the 1984–1987 period, relevant to each specialized area. Many of these findings are to be found in English abstracts in the USSR Space Life Sciences Digest, a bimonthly compendium of Soviet research prepared for NASA's Life Sciences Division.

## BIOMEDICAL FINDINGS

### *Cardiovascular Changes*

A report by Dr. Oleg Atkov detailed the results of echocardiographic studies conducted on 15 cosmonauts in seven prime crews of Salyut-6 and -7 missions lasting from 75 to 237 days. Taken together, the studies showed a decrease in stroke ejection time caused by a decrease (about 25 percent) in left ventricular volume; this returns to normal postflight. There was no concomitant change in contractility. During the longest mission (237 days), no progressive deterioration in heart rate, blood pressure, or heart muscle size was noted. Atkov concluded that intracardiac hemodynamics, at rest, remain stable over a flight of this length. He also concluded that the reduced orthostatic tolerance postflight does not result from a deterioration of the functional state of the myocardium. Observed hemodynamic changes appear to result from the decrease in circulating blood volume, rather than from any disorder in myocardial contractility.[259]

A study of results of the 211-day mission in 1982, published in 1984, showed a decrease in pulsed blood perfusion in the brain, a change that was partly compensated for by an increase in heart rate. Other results agreed with those noted above.[260]

Because of the requirement for non-invasive measurement techniques, few inflight cardiovascular studies were performed on cosmonauts until the last decade, when ultrasonic techniques were improved and modified for use in space. Important advances were made by the French with their "Echograph" device for use on the seven-day French-Soviet flight in 1982.[261] Results of ultrasonic investigations on that mission showed that antiorthostatic bedrest is a better simulation of microgravity with respect to cardiac hemodynamics and cerebral circulation than it is with respect to inferior-limb circulation.[262]

Soviet scientists have experimented with a variety of pharmacological agents for treating cardiovascular deconditioning, including antihypoxic agents, neurological substances, beta blockers, and sympatholytic and myotropic substances. To counter postflight orthostatic intolerance, antidiuretics have been used. But because that condition is associated not so much with a decrease in overall blood volume as it is with low blood volume in the upper body, a drug that has a vasopressor effect on the lower limbs might be effective. One such is sydnocarbium, which has no effect on subjects in a horizontal position, but is effective (for arteries) in the vertical position. To enhance pressor reactions in the veins, the drug glivenol (trimvenol) shows promise of being effective.[263]

### *Muscle and Bone Changes*

The underloading of antigravity muscles in microgravity results in their partial atrophy or subatrophy, mass loss in some muscle groups, and atonia of the posterior group of calf muscles. It also yields a decreased threshold of vibration sensitivity in the support areas of the feet and the tendon T-reflex of the gastrocnemius muscle, as well as an increase in protein catabolism which seems to cause an accelerated discharge of potassium from the muscles.[264]

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[259] Atkov, O. Yu. The State of Cosmonauts' Cardiovascular Systems During Long-Term Orbital Flights. Byulleten' Vsesoyuznogo Kardiologicheskogo Nauchnogo Tsentra AMN SSSR, VIII(2), 1985, pp. 97–100.

[260] Gazenko, O. G. and A. D. Yegorov. Preliminary Results of Medical Research During a 211-day Space Flight. In Biological Issues in the Works of K. E. Tsiolkovskiy and Their Development in Modern Cosmonautics: Papers presented at the XVIII-XIXth lecture series dedicated to further development of the ideas of K. E. Tsiolkovskiy (Kaluga, 1983 and 1984). Moscow, 1985. [Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 13, September 1987, pp. 101–106.]

[261] Atkov, O. Yu., et al. Ultrasound Techniques in Space Medicine. Aviation, Space, and Environmental Medicine, 58(9), 1987, pp. A69–73.

[262] Pottier, J.M., et al. Cardiovascular System and Microgravity Simulation and Inflight Results. Presented at the 35th Congress of the International Astronautical Federation, Lausanne, Switzerland, October 7–13, 1984.

[263] Shashkov, V. S. and A. Yu. Modin. Problems and Prospects in Pharmacological Correction of Orthostatic Intolerance in Space Medicine. Kosmicheskaya Biol. i Aviak. Medit., 20(5), 1986, pp. 4–11.

Nevertheless, results of the 237-day mission showed that changes in antigravity muscles were small (on the order of 10–15 percent) and that, although those changes occurred rapidly during the initial phase of flight, they soon stabilized. In the same flight, motor coordination and work capacity of muscles showed only slight changes. This crew's postflight readaptation proceeded ahead of the normal schedule; motor disturbances had disappeared by the eleventh day postflight.[265]

Soviet studies have shown that osteoporosis of bone is produced by increased renal excretion of phosphates and calcium, as well as losses of hydroxyproline and nitrogen.[266] After six-month flights aboard Salyut 6, mineral losses in the calcaneus ranged from 3.2% to 8.3%; however, this was said to be less than the losses seen after comparable periods of bedrest.[267] After the 237-day flight in 1984, minimal losses were seen in the calcaneus and femur, with no significant change being seen in the mineral content of the lumbar vertebrae.[268] The Soviets have concluded that, with existing countermeasures, bone loss either plateaus or is prevented entirely. However, based on reanalysis of Soviet data from the 211-day flight in 1982 (the latest data available), some U.S. scientists are not certain that bone loss levels off.[269]

In a study using immobilized rats, the drug hydroxydimethylaminopropylene diphosphonic acid (HMADPA) was shown to be an effective countermeasure to osteoporosis. It led to inhibition of both growth and resorption of bone; but since the inhibition of resorption was stronger, the density of spongy bone increased.[270]

### *Fluid-Electrolyte, Metabolic and Hormonal Changes*

Modern techniques of clinical analysis permit extensive biochemical study of blood, urine, and other body fluids. Samples have been taken before, during, and after spaceflights of various lengths to determine the effects of stress, reduced activity, and other factors on different metabolic parameters. Ground-based studies on humans and animals complement these flight studies. Evidence of stress is seen in the presence of certain corticosteroids.[271] Certain changes in metabolism have been observed, but these do not appear to be of great physiological significance. A major review by leading Soviet space medicine specialists summarizes the results of 20 years of research in this area in flight (both piloted spacecraft and biosatellites) and on the ground.[272]

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[264] Gazenko, O.G., et al. Man in Space Flight, op. cit.

[265] A Doctor in Space. Soviet Life, April 1985.

[266] Gazenko, O. G., et al. Fluid-electrolyte Homeostasis and Space Flight. In Problems of Space Biology (vol. 54). Moscow: Nauka Press, 1986.

[267] Gazenko, O.G., et al. Man in Space Flight, op. cit.

[268] Gazenko, O.G., et al. Review of Basic Medical Results of the Salyut-7-Soyuz T-8 8-month Manned Flight. Presented at the 37th Congress of the International Astronautical Federation, Innsbruck, Austria, October 4-11, 1986.

[269] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

[270] Kaplanskiy, A.S., et al. Effects of Diphosphonates on Development of Osteoporosis in Rats Undergoing Hypokinesia. Kosmicheskaya Biol. i Aviak. Medit., 21(1), 1987, pp. 47-51.

[271] Tigranyan, R. A. Metabolic Aspects of the Problem of Stress in Space Flight. In Problems of Space Biology (v. 52). Moscow, Nauka Press, 1985.

Changes in fluid-electrolyte metabolism in space include partial water losses, increased renal excretion of certain electrolytes (including potassium, calcium, and phosphorus), and reduction of plasma volume and interstitial fluid volume. An important contributor to these changes is the variations seen in the activity of the renin-angiotensin-aldosterone system.[273] Another contributor, particularly in the case of the negative potassium balance, seems to be a decrease in the potassium-pooling capacity of the muscles due to their atrophy and mass loss.[274]

In results of the 211-day mission in 1982, a number of metabolic-hormonal changes were identified for the first time. The principal ones were: decreased activity of the enzyme acetylcholinesterase; increased concentration of a number of free amino acids in blood plasma; increased concentration of reduced glutathione; and depression of the rate of glycolysis in erythrocytes. Gazenko and Yegorov believe that a significant decrease seen in oxidase activity in the blood, seen after many long-term flights, could reflect a decrease in the rate of the oxidative component of metabolism. The increased level of free amino acids suggests the predominance of catabolic over metabolic processes, they believe.[275]

In another important study, metabolic and hormonal parameters were examined in 20 cosmonauts who participated in short-term flights of 4–14 days. A typical feature of the adaptation to this level of exposure is the transition to a new level of hormonal regulation with a significant increase in the production of glucocorticoids, catecholamines, and components of the renin-angiotensin-aldosterone system; also seen are a modification of the activity of tissue hormones and fluid-electrolyte homeostasis, and a simultaneous increase in insulin secretion that diminishes the metabolic effects of glucocorticoids and catecholamines.[276]

An interesting Soviet advance was made in the mathematical modeling of the processes by which fluid-electrolyte balance is altered under extreme conditions such as space flight.[277]

### *Hematology*

The average lifespan of red blood cells (RBCs) is approximately 120 days. Therefore, the results of hematologic studies made on the 211-day mission are of unusual interest, since this flight represented nearly two generations of RBCs. If weightlessness disrupted RBC formation, then "space anemia" should become pronounced. However, investigation showed only a temporary, relatively slight decrease in the number of RBCs, which gradually returned to normal postflight (over a 1.5–2 month period). The decrease in RBCs is constant in flights of this length, in comparison to shorter flights. The results of these studies have made Soviet researchers confident of the blood system's capacity to adapt to long-term space flight and to recover afterward.[278] [279]

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[272] Gazenko, O. G., et al. Fluid-electrolyte Balance and Space Flight. Moscow, Nauka Press, 1986. In Problems in Space Biology (v. 54).

[273] Gazenko, O.G., et al. Review of Basic Medical Results of the Salyut-7-Soyuz T-8 8-month Manned Flight, op. cit.

[274] Gazenko, O.G. and A.D. Yegorov. Preliminary Results of Medical Research During a 211-day Space Flight, op. cit.

[275] Ibid.

[276] Grigoriev, A. I., et al. Metabolic and Hormonal Status of Crewmembers in Short-term Spaceflights. Aviation, Space, and Environmental Medicine, 58(9, Suppl.), 1987, pp. A121–125.

[277] Grigoriev, A. I. and V. V. Verigo. Mathematical Modeling of the Processes of Fluid-electrolyte Exchange. Kosmicheskaya Biol. i Aviak. Medit., 20(2), 1986, pp. 24–27.

Results of blood studies done on the 237-day flight in 1984 showed a slight increase (10–15 percent) in total blood calcium, an increase in parathyroid hormone, and a decrease in calcitonin—findings consistent with a continued gradual loss of bone mineral.[280]

### *Immunology*

The Soviets have long been concerned with possible changes in the immune system as a result of space flight. Flight studies have involved both humans and animals. Ground-based studies have often employed pilots and athletes as analogs.[281] In cosmonauts, a modest decrease in some parameters of natural immunity has been seen, along with an increased concentration of microbes on the skin and mucosa, some dysbacteriotic changes, and an increased antibiotic resistance and pathogenicity of certain microorganisms. These changes in the biocenosis between humans and microorganisms were not correlated with flight time and were primarily controlled by such factors as cleanliness, diet, and individual variability of both the crewmembers and microorganisms.[282]

Results of immunological studies on the 211-day mission showed a decrease in T-lymphocytes (blood cells responsible for immunity) and a reduction in their functional activity. There were also disruptions in immune system regulation, as shown by a decrease in T-helper activity and activation of T-suppressor lymphocytes. Lowered natural resistance of the cosmonauts portends an increased risk of infection in the early postflight period.[283]

### *Psychology*

The importance of psychology (both research and applications) in the Soviet space program was discussed under several of the topics in the previous section of this chapter. This work is distributed across a range of specialty areas. Many of the studies and theories seem rather arcane to Western space medicine specialists; others are largely common-sensical. Some examples are given below.

One key area of research is on psychological tests for use in selection of cosmonauts and crews. A recent study proposes a crew selection methodology based on a variety of measures of social adjustment and interpersonal behavior.[284]

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[278] Gazenko, O.G. and A.D. Yegorov. Preliminary Results of Medical Research During a 211-day Space Flight, op. cit.

[279] Vorobyov, E. I., et al. Medical Results of Prolonged Salyut-6 Manned Flights. Kosmicheskaya Biol. i Avia. Medit., 18(1), pp. 14–29.

[280] Gazenko, O.G., et al. Review of Basic Medical Results of the Salyut-7-Soyuz T–8 8-month Manned Flight, op. cit.

[281] See, for example, Surkina, I.D., et al. Changes in Immunity Under Stress. Fiziologiya Cheloveka, 12(3), 1986, pp. 460–464. [Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 8, October 1986, p. 53.]

[282] Gazenko, O.G., et al. Man in Space Flight, op. cit.

[283] Gazenko, O.G. and A.D. Yegorov. Preliminary Results of Medical Research During a 211-day Space Flight, op. cit.

[284] Marischuk, V.L. and V.I. Yevdokimov. Theoretical Basis for a Social Psychological Selection System for Flight Crews. Kosmicheskaya Biol. i Aviak. Medit., 21(2), 1987, pp. 4–7.

Another important area focuses on cosmonaut/crew performance—its measurement, diagnosis, and enhancement. Soviet psychologists have developed a set of methods for diagnosing and predicting three types of human characteristics or variables considered to be the most relevant to flight performance: work capacity, fatigue, and stress.[285] Studies of operators in industrial and other settings are used to develop diagnostic and measurement tools that could be relevant to the spaceflight work regime; monotony, time pressure, and teamwork are frequent subjects of study.[286]

Performance under stress is a topic of particular interest. Pilots and air traffic controllers are often studied, since their work is closely analogous to that of cosmonauts. The studies may take physiological responses into account, or may be purely psychological.[287] [288] A wide range of stressors are employed experimentally, including sleep deprivation and drugs.[289] Measures of emotional stress are sought that could be used in space. Galvanic skin response is one commonly studied measure.[290] Heart rate is another.[291]

One theory regarding the relationship between stress and performance is the "need-information" theory. Espoused by its Soviet author, P. Simonov, at a NASA symposium in 1986, this theory postulates that the origin, nature, and intensity of emotions are determined jointly by a felt need and a subjective assessment of the probability of satisfying that need. Simonov uses his theory to derive recommendations for preventing excessive emotional stress and its potentially adverse effects on cosmonaut performance. Maximum saturation with useful information is the key, he believes.[292]

Research on the effects of psychological factors on physiological parameters (and vice versa) is defined as "psychophysiology." Because it is so broad, this rubric covers a significant portion of the Soviet research in space medicine. The scope of the field and some key findings are described in a 1985 book.[293]

The Soviets also study various approaches to work/rest scheduling. Litsov and Shevchenko analyzed the effect of cosmonaut work-rest cycles on their well-being, and recommended that the work schedule be coordinated with cosmonaut biorhythms.[294]

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[285] Simonov, P. V. Monitoring Man's Work Capacity in Aviation and Space Flight. Paper presented at the NASA Space Life Sciences Symposium, Washington, D.C., June 21-26, 1987.

[286] Zabrodin, Yu. M. (Ed.). Problems in Diagnosis and Control of the State of Human Operators. (Abstracts of Scientific Papers of an All-Union Conference) Moscow, Central Committee of the USSR Society of Psychologists, 1984.

[287] Tereplyak, Ya. et al. Resistance of Psychomotor Performance to Anticipatory Stress in Pilots With Varying Anxiety Levels. Kosmicheskaya Biol. i Aviak. Medit., 19(4), 1985, pp. 24-26.

[288] Kan, Ye. L., et al. Biochemical Parameters of Emotional Stress in Air Traffic Controllers. Kosmicheskaya Biol. i Aviak. Medit., 20(4), 1986, pp. 22-25.

[289] Medvedev, V. I., et al. Mechanism Underlying Voluntary and Involuntary Regulation of Human performance Under Extreme Conditions. Fiziologiya Cheloveka, 11(3), 1985, pp. 463-469. [Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 11, May 1987, pp. 107-108.]

[290] Rakov, G. K. and Yu. A. Fadeyev. Using Galvanic Skin Response to Estimate Emotional Stress During Job Performance. Fiziologiya Cheloveka, 11(3), 1985, pp. 463-469. Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 3, December 1985, p. 57.

[291] Simonov, P. V. Some Theoretical Principles for Evaluating and Developing Methods for Controlling and Compensating for the Effects of Emotions on Cosmonaut Performance. Uspekki Fiziologicheskich Nauk, 17(2), 1986, pp. 20-30. [Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 7, August 1986, pp. 86-87.]

[292] Ibid.

[293] Khachatur'yants, L. S. and Ye. V. Khrunov. Conquering Weightlessness. Moscow, Znaniye, 1985. [Described in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 11, May 1987, p. 110.]

### *Neurophysiology and Space Motion Sickness*

As was described in the earlier section "Adaptation to Space, Readaptation to Earth," the most troublesome problem attending the early or acute phase of adaptation to microgravity is space motions sickness. Only a degree of progress has been made, in recent years, toward understanding the etiology of this condition. Soviet researchers now believe that the observed changes in vestibular function and vestibular interaction, as well as the decrease seen in the threshold of nystagmus (eye-rolling), early in flight indicate an increased dynamic excitability of the semicircular canals. Conversely, inhibition of the eye-tracking function in cosmonauts at rest appears to suggest a decreased static excitability of the canals.[295] [296] [297] Current theories and possible mechanisms of SMS are discussed in a recent survey by two noted Soviet researchers.[298]

Measurement of ocular counter-rolling, or nystagmometry, has received considerable attention as a diagnostic technique for studying the vestibular apparatus. A book has been published which examines past findings in detail and explores the uses of nystagmometry in research and diagnosis.[299]

An interesting series of biosatellite experiments were carried out on the effect of spaceflight conditions on the morphogenesis (development) and structure of the vestibular apparatus in amphibian and fish larvae. Both proceeded normally in microgravity. Vinnikov and his colleagues concluded that gravity is not a necessary condition for the development of a gravity receptor—even though, in some species, the vestibular apparatus evolved in response to gravity.[300]

### *Radiobiology*

Because of the cumulative nature of radiation injury, the dangers of space flight increase as the total exposure to radiation from solar particles and galactic cosmic rays grows. Inside the Earth's radiation belts, the received dose of radiation can reach 14-15 millirem per day. Outside the belts, trapped solar radiation decreases and the main danger is from galactic cosmic rays and solar flares. In the United States, the accepted dose of ionizing radiation for a human on the ground is 5 rem/year; for astronauts, it is 50 rem/year because it is considered an occupational hazard.[301] There is little likelihood of significant radiation damage during relatively short duration flights in low Earth orbit, but there is a high risk of damage in long duration interplanetary flights.[302] While shielding can be effective for protection from solar particles, no adequate measure for protecting against galactic cosmic rays has yet been developed.[303]

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[294] Litsov, A. N. and V. F. Shevchenko. Psychophysiological Characteristics of the Organization and Scheduling of Daily Activity Cycles of Crews on Long-term Space Flight. Kosmicheskaya Biol. i. Aviak. Medit., *19*(2), 1985, pp. 12-16.

[295] Kornilova, L.N., et al. Ocular Responses Induced by Vestibular and Visual Stimulation in Weightlessness. In Proceedings of the International Symposium on Ophthalmoneurootology (vol. 1),Budapest, Hungary, 1985, pp. 65-70.

[296] Kozlovskaya, I.B., et al. Adaptation Mechanisms in System of Vestibulo-oculomotor Interaction to the Changes of Vestibular Function, 1986, op. cit.

[297] Sirota, M. G., et al. Effects of Microgravity on the Vestibular Function. In Proceedings of the 14th Meeting of the Socialist Countries Joint Working Group on Space Biology and Medicine, Havana, Cuba, April 5-12, 1986.

[298] Yegorov, A. D. and Y. M. Yuganov. Labyrinthine and Extralabyrinthine Mechanisms of Development of Motion Sickness in Weightlessness. Kosmicheskaya Biol. i Aviak. Medit., 19(2), Mar-Apr 1985, pp. 4-11.

[299] Levashov, M. M. and V. A. Kislyakov. Problems of Space Biology, Vol. 50: Nystagmometry for Evaluation of the Status of the Vestibular Function. Leningrad, Nauka Press, 1984. (NASA TM-77616; NTIS HC A11/MF)

[300] Vinnikov, Y.A., et al. The Development of the Vestibular Apparatus Under Conditions of Weightlessness. Zh. Obshchey Biol., 44(2), 1983, pp. 147-163. (Available as NASA TM-77517; NTIS HC A03/MF)

The Soviets pursue extensive studies on the amounts and effects of different types of biologically active radiation and ways to protect against it. A major set of experiments were those conducted aboard Salyut 6, and reported in 1986.[304] The "Integral" experiment studied the distribution of the absorbed dose of CR and the flux of heavy charged particles (HZE) over a three-year period, using various detectors. The energy range of protons incident on the station was determined to be 20–1000 MeV. For this range, the radiation dose absorbed by each crewmember was calculated to be 0.01 Gy/R.[305]

The "Pille" experiment, also on Salyut 6, tested a method for studying dose distribution and determining individual doses in a short period of time. Pille sensors were placed in various locations throughout the spacecraft and also on the cosmonauts' flight suits, for five days at a time. Results showed that the mean dose rate was nearly the same throughout the flight, suggesting that the dose was mainly attributable to HZEs. The dose measured on cosmonauts' clothing was 15–20 percent lower than elsewhere in the station, a result of shielding by the body.

Another experiment was performed (by a Romanian cosmonaut) to study changes in charged particles along the orbital routes that passed through the South Atlantic anomaly, so as to determine the contribution of the Earth's radiation belt to the overall dosage. Results showed that the flux density of charged particles increased by as much as 20 times when the station passed through the central portion of the anomaly. From this information, it was calculated that the energy of protons on board the station was approximately 220 MeV.[306]

A considerable variety of studies dealing with radioprotection were reported during 1984–1987. Two separate studies demonstrated the radioprotective effects of a constant magnetic field on bacteria and rats.[307] [308] The radioprotective effect of a Hungarian patented drug known as "polyanion" was tested in rats. It showed a radioprotective effect on the spleen and bone marrow, decreasing the amount of early radiation damage to hemopoietic tissue.[309] Different combinations of the radioprotective drugs APAETP and mexamine were studied; the most effective combinations were found to be a high dose of APAETP and either a low or high (i.e., not moderate) dose of mexamine.[310]

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[301] McCormack, P. NASA Life Sciences Division. Personal communication, January 4, 1988.

[302] Lanzerotti, et al. Soviet Space Science Research, op. cit., p. V–20.

[303] McCormack, op. cit.

[304] Atakov, Yu.A., et al. Radiation Research in Flight. In (N. N. Gurovskiy, Ed.) Results of Medical Research Performed on the "Salyut-6"-"Soyuz" Space Station Complex. Moscow, Nauka, 1986. Abstracted in L. Hooke et al., Eds., USSR Space Life Sciences Digest, No. 13, September 1987, pp. 80–87.

[305] MeV = million electron-volt. Gy/R = Gray/Roentgen; one Gray = 100 rad.

[306] Ibid.

[307] Pantev, T.P. and M.I. Minkova. Direct and Indirect Effects of a Constant Magnetic Field on Biological Subjects. Kosmicheskaya Biol. i Aviak. Medit., 20(6), 1986, pp. 73–76.

[308] Minkova, M.I. and T.P. Pantev. Radiosensitivity of Intestinal Bacilli After Exposure to a Constant Magnetic Field. Kosmicheskaya Biol. i Aviak. Medit., 20(6), 1986, pp. 90–91.

A book appeared, authored by two notable Soviet researchers, which offers a comprehensive discussion of radiation effects, acceptable dose levels, and protection in various kinds of aerospace vehicles.[311]

### *Nutrition*

New concepts regarding digestive physiology were explained by Dr. Oleg Gazenko in an address to the U.N. Committee on the Peaceful Uses of Outer Space in February 1987.[312] He described "a recently developed branch of medicine—"trophology"—as the study of general principles of fundamental vital processes of living systems, such as ingestion, processing, and assimilation of nutrients. Several discoveries in this area were outlined:

1. In addition to the recognized extracellular and intracellular types of digestion, there are also two others: (a) intracellular digestion occurring in vacuoles; and (b) membrane digestion occurring on the surfaces of cells of the gastrointestinal tract.
2. New information has been gained regarding the immunological defense systems of the small intestine.
3. Research has shown that dietary fiber is essential to good digestive functioning and overall health.
4. Support of proper endoecology (i.e., microbiology of the digestive tract) is now recognized as one of the more important tasks in medical support of long-term space flight. Methods have been developed for evaluating and regulating cosmonauts' microflora.
5. Endocrine components of the digestive system produce some 30 hormones and hormone-like substances. It has recently been shown that among these are hormones with general (rather than local) effects—e.g., the polypeptides.

Gazenko expects trophology to permit nutritionists to advance beyond the accepted concept of "a balanced diet" to the new one of "adequate nutrition."

In other findings, decreases seen in essential amino acids in cosmonauts after the 211-day mission led researchers to the conclusion that the preflight diet should be supplemented with methionine and aspartic acid, and the flight and postflight diets with seven essential amino acids plus cystine, arginine, proline, and aspartic acid.[313]

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[309] Minkova, M.I., et al. Radioprotective Effect of Insoluble Polyanion in Prolonged Exposure to Gamma-radiation. Kosmicheskaya Biol. i Aviak. Medit., 20(6), 1986, pp. 92-93.

[310] Vladimirov, V.G., et al. Optimization of the Composition of the Radioprotective Compound APAETP + Mexamine and Study of Its Action. Radiobiologiya, 26(4), 1986, pp. 495-498. Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 10, March 1987, pp. 82-83.

[311] Vorob'yev, Ye.I. and Ye.Ye. Kovalev. Radiation Safety of Flight Vehicle Crews. Moscow, Energoatomizdat, 1983. [Described in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 4, February 1986, pp. 107-108.]

[312] Gazenko, O.G. Space Medicine—New Approaches in the Theory and Practice of General Medicine. Presentation of the Soviet delegation at the 24th Session of the Science and Technology Subcommittee of the U.N. Committee on Peaceful Uses of Outer Space, United Nations, New York, February 1987.

## OPERATIONAL MEDICINE

As was pointed out at the beginning of this section, operational medicine involves the provision of medical support to space crews on the ground and in flight. It is oriented not so much toward research as toward application of the results of research. Defined at its broadest, operational medicine includes in its scope such activities as crew selection and training, optimization of the spacecraft environment and life support, medical monitoring and instrumentation, medical treatment, provision of countermeasures, and work/rest scheduling. Most of these activities have been described elsewhere in the chapter. The following discussion describes only those elements that are specific to the provision of medical care to space crews: i.e., medical monitoring/instrumentation, and medical treatment.

### *Medical Monitoring and Instrumentation*

Piloted space flight was first proven practicable when the dog Laika was electronically monitored during her 1957 flight aboard Sputnik 2. Since that time, remote electronic medical monitoring has been extensively utilized by the United States as well as the Soviet Union in both the piloted space missions and biological experiments. For monitoring cosmonauts, the Soviets have developed a wide range of physiological tests and bioinstrumentation. Such vital functions as heart and respiratory rate are monitored by electrocardiography (EKG) and seismocardiography. Blood flow is observed by echo-, vector-, and ballistocardiography and plethysmography. Various rheographic techniques are used to measure fluid shifts in different parts of the body. Electroencephalographic (EEG) measures of the brain, electroculographic and nystagmometric measures of eye motion, electromyographic measures of muscle electric potential, and thermographic measurements of the body have all been made inflight and telemetered to Earth. Certain technical data that impinge on physiological function, such as cabin temperature, humidity, atmospheric pressure, and gas composition in the space cabin are also monitored continuously.[314]

Space medicine specialists maintain a rigorous medical overview of all piloted space flights and of each cosmonaut, from preflight through the completion of readaptation well after the flight. Inflight, cosmonauts are monitored closely from the ground during rest as well as during physical load such as exercise. This nearly continuous surveillance is vital for several reasons. First, it is necessary to ensure that the physiological parameters of the cosmonauts do not range outside the known, experienced, and/or baselined ranges without close attention being paid to that fact; it is thus essential in determining when countermeasures are needed. Second, it is invaluable for collecting data used in continuing biomedical studies; visiting crews are often used as control subjects, and to return samples for analysis. Third, it is valuable in determining the effects of repeated long-duration flights. Fourth, and very importantly, it is necessary for determining the fitness of cosmonauts to perform extravehicular activity. The EVA suit itself, as was described earlier, has a considerable capability for monitoring the physiological parameters of its wearer.

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[313] Popov, I.G. and A.A. Latskevich. Blood Amino Acids of Cosmonauts Before and After 211-day Spaceflight. Kosmicheskaya Biol. i Aviak. Medit., *18*(6), November-December 1984, pp. 11-17.

[314] U.S. Congress. Soviet Space Programs: 1976-80, op. cit., pp. 686-687.

Medical monitoring of a flight was greatly enhanced on the 237-day Soyuz T-10/T-11 mission by the presence of a medical doctor, Oleg Atkov. Having Atkov in attendance as cosmonaut-physician made for several advantages, as noted in Chapter 2. For the first time, intravenous blood samples could be drawn; maximum LBNP loads could be tested in the Chibis suit; medical studies could be conducted on a more flexible schedule; the exercise regimen could be made more rigorous, under direct medical supervision; and record EVAs (both in number and duration) could be made with greater confidence.[315]

*Medical Treatment*

Current provisions for direct medical care on Soviet missions inflight are quite limited. Cosmonauts are trained in the administration of basic first aid, and medical specialists on the ground attempt diagnosis and prescription, as necessary, from onboard medical supplies. The onboard medical kit consists of medication used to counteract:

motion sickness
fatigue
nasal congestion
bacterial infection
pain
diarrhea
minor lacerations

Also included in the kit are:

vitamins
heart drugs
medicines for respiratory irregularities
tranquilizers
sleeping pills
drugs to reduce internal stress
biphydumbacterin
lactobacterin (for maintenance of intestinal lactoflora [illegible]ng antibiotic therapy)

Most of these medications are taken in pill form. For those requiring injection, disposable syringes are included in the medical kit. However, provisions for medical treatment inflight are clearly not extensive.[316] [317] There is no indication that these provisions have changed on the Mir station.

In view of the long duration of their flights, however, the Soviets have given serious attention to protocols and equipment necessary in the event of medical emergencies that might require surgery and/or resuscitation.[318] They have concluded that traditional methods of emergency medicine are not applicable in the special environment of a spacecraft. Providing general anesthesia, either by inhalation or injection, would not be practicable due to environmental and physiological considerations. Therefore, they have focused on local anesthesia techniques, including such unconventional measures (by Western medical standards) as the use of auriculoacupuncture combined with electroanalgesic stimulation. However, surgery is considered a last resort; the preferred approach would be, if possible, to use local hypothermia and to return the individual to Earth as soon as possible.

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[315] Gazenko, O.G., et al. Review of Basic Medical Results of the Salyut-7-Soyuz T-8 8-month Manned Flight, op. cit.

[316] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 691.

[317] Ryumin, V. Ryumin Comments on Flight of Salyut-7, op. cit

Nevertheless, assuming that the need for surgical intervention in space may one day arise, the Soviets have developed lightweight surgical equipment and associated sterilization techniques, and have explored the development of soft sterile containment chambers for performing surgery in space. They also have some advanced ideas about devices that could be used to separate gas bubbles from blood, outside the body, about sorption techniques for detoxifying body fluids (e.g., as in dialysis), and about the use of blood substitutes.[319]

## SPACE BIOLOGY

Several key points can be made about the Soviet space biology program. First, the range of spaceflight opportunities available to them allows the Soviets to devote considerably more effort and resources to their program than the U.S. does. Nearly all piloted missions to Soviet space stations include biological materials and experiments; non-human organisms ranging from microorganisms to insects, plants and seeds, and vertebrates have been studied aboard these stations.[320] In addition, dedicated biological satellites in the Cosmos series (termed "biosatellites") have been flown frequently and regularly—i.e., roughly every two years on average since the mid- 1960s. These spacecraft have carried a veritable Noah's Ark of biological materials including, in addition to those already named, tissue cultures, amphibians, fish, bird eggs, turtles, and primates (rhesus monkeys).

The Soviet space biology program is clearly a carefully thought-out program of incremental advances across a broad front. For example, after a biosatellite mission in 1983 (Cosmos 1514) established that the rhesus monkey is an adequate model for exploring the mechanisms of physiological adaptation to microgravity of the cardiovascular and vestibular systems, two subsequent biosatellite missions (Cosmos 1667 and 1887) pursued very similar sets of experiments with monkeys, building slowly on the knowledge gained in the first flight.[321]

The second major point is that the Soviet space biology program is clearly designed to support the overall Soviet goal of unlimited human habitation in space. There is no great separation between biological data and human data. Soviet space biology experiments are all directed at helping to solve problems associated with either: (a) human physiological response to space flight or (b) development of closed-environment life support systems (which are themselves intended to support human presence in space).[322]

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[318] Stazhadze, L.L., et al. Anesthesia, Surgical Aid and Resuscitation in Manned Space Missions. ACTA Astronautica, No. 8, 1981, pp. 1109–1131.

[319] Ibid.

[320] Dubinin, N.P. (Ed.). Biological Studies on the Salyut Orbiting Stations. Moscow, Nauka Press, 1984. (Available as NASA TM -77627)

[321] Sandler, H., et al. Cosmos 1514 and 1667: Comparison Report of Primate Cardiovascular Experiment. Prepared by NASA for Institute of Biomedical Problems, Moscow, October 10, 1986.

### BIOSATELLITE MISSIONS

During the period 1984–1987 a variety of biological studies were conducted onboard Salyut 7 and Mir. During the Soyuz T–10/T–11 prime mission to Salyut 7, for example, crews conducted cytological studies on microorganisms (*Citos–3*), plant growth experiments (*Substrat, Oazis, Vazon,* and *Biogravistat*), and a radiation experiment (*Meduza*) (as described in chapters 2 and 3).

However, by far the most interesting biological work took place aboard a series of biosatellites. The first of the series, Cosmos 1514, actually flew in December 1983; but findings were not reported until well into the current period. Indeed, due to the publication and translation lags significant findings were still appearing in 1987. The second flight in the series, Cosmos 1667, occurred in July 1985. Preliminary Soviet findings from that mission only began to appear in 1986, and complete results were still not available in English as of late 1987. On that basis, Soviet findings from the third flight in the series, Cosmos 1887 (which flew for 14 days in September-October 1987) should not be expected until mid–1988 and later. Therefore, Soviet biological findings summarized later in this section will be derived from Cosmos 1514 and 1667 (and from the broad base of knowledge established by even earlier biosatellite mission).

The experiments on these three missions are listed in Tables 15, 16, and 17. (Table 17 lists only those experiments involving U.S. investigators.) U.S. investigators participated in all three missions, although due to the lapsing (in 1982) of the U.S.-Soviet intergovernmental agreement for cooperation in space research, only one U.S. investigator participated in the 1985 mission. Cosmos 1514, in 1983, was a truly international mission, carrying experiments from nine countries, including four from the United States with numerous U.S. and Soviet co-investigators on each of the four.[323] (This cooperation was permitted to continue because the plans for it had been made before the agreement expired.) Likewise, Cosmos 1887, in 1987, once again featured substantial U.S. participation, with 24 U.S. experiments onboard.

Cosmos 1514 was notable for being the first Soviet mission carrying non-human primates—two rhesus monkeys (Macaca mulatta). It was briefer than preceding missions (five days) because the monkeys were present. More than 60 experiments were performed on the various biological subjects. Unique hardware developed for the mission included the BIOS primate capsule, a combined life support, restraint, and experiment system (shown in Figure 3). The

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[322] Lanzerotti, L.J. Soviet Space Science Research, op. cit.

[323] Mains, R.C. and E.W. Gomersall (Eds.). Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514 (NASA TM–88223). Moffett Field, CA, NASA Ames Research Center, May 1986.

U.S. supplied implantable instrumentation for measuring carotid blood flow and pressure. The primary purposes of the mission were to: (1) test the primate model as a surrogate for human cardiovascular and vestibular adaptation to microgravity and (2) examine the effects of microgravity on gestation and development of rats and fish.[324]

Only one monkey was instrumented with the blood pressure/flow cuff; EKG and several other parameters were monitored on both animals. As is customary in all Soviet biosatellite missions, synchronous ground control experiments were run for all flight experiments.[325]

TABLE 15.—COSMOS 1514 EXPERIMENTS

| Organism | Sample size | Experiments |
|---|---|---|
| Rhesus monkeys | 2 | Cardiovascular adaptation [1] |
| | | Chair oscillation, Operant tasks |
| | | Neurophysiology |
| | | Biorhythm measurements [1] |
| | | Calcium metabolism [1] |
| Pregnant rats | 10 | Embryology [1] |
| Pregnant fish | 3 | Embryology |
| Maize seeds | 14 | Metabolic activity |
| Crocus plants | | Development (flowering) |

[1] U.S. participation.

Source: Gazenko, O.G. and Eu.A. Ilyin. Investigations On-board the Biosatellite Cosmos-83. Advanced Space Research, 4(10), 1984, pp. 29–37.

TABLE 16.—COSMOS 1667 EXPERIMENTS

| Organism | Sample size | Experiments |
|---|---|---|
| Rhesus monkeys | 2 | Cardiovascular adaptation [1] |
| | | Chair oscillation, operant tasks |
| | | Neurophysiology |
| Male rats | 10 | Morphology and histochemistry |
| | | Biochemistry |
| | | Reproductive function and remote effects |
| Newts | 10 | Tissue regeneration, cell division |
| Fruit flies | 1500 | Energy metabolism |
| Fish (guppies) | 3 | Development |
| Maize seeds | | Seedling structure and function |
| Iris plants | | Flowering characteristics |
| | | Cytogenesis |

[1] U.S. participation.

Source: American Society for Gravitational and Space Biology Newsletter, 1(2), September 1985, pp. 2, 4.

TABLE 17.—*Cosmos 1887 Experiments With U.S. Participation*

Bone and muscle:

1. Biochemical Studies of Bone Matrix and Mineral in the Femur of Growing Rats in Space
2. Biomechanical, Biochemical, and Morphological Alterations of Muscle and Dense, Fibrous Connective Tissues During 14 Days of Space Flight

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[324] Gazenko, O.G. and Eu.A. Ilyin. Investigations On-board the Biosatellite Cosmos-83. Advances in Space Research, 4(10), 1984, pp. 29-37.

[325] Sandler, H., et al. Cardiovascular Results From a Rhesus Monkey Flown Aboard the Cosmos 1514 Spaceflight, and Ground-based Controls. In R.C. Mains and E.W. Gomersall (Eds.), Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514 (NASA TM-88223). Moffett Field, CA, NASA Ames Research Center, May 1986.

3. Gravity and Skeletal Growth
4. Trace Element Balance in Rats During Space Flight
5. Effect of Space Flight on the Maturation of Bone Mineral in the Axial and Appendicular Skeletons and in the Mandibles of the Rat
6. Morphometric and EM Analyses of Tibial Epiphyseal Plates From Cosmos '87 Rats
7. Metabolic and Morphologic Properties of Muscle Fibers After Space Flight
8. Skeletal Muscle Atrophy in Response to 14 Days of Weightlessness
9. Morphological, Histochemical, and Biochemical Investigation of Microgravity-induced Nerve and Muscle Breakdown
10. Effect of Zero Gravity on Myosin Isoform Expression in Rodent Skeletal Muscle
11. Messenger RNA Levels in Skeletal Muscle

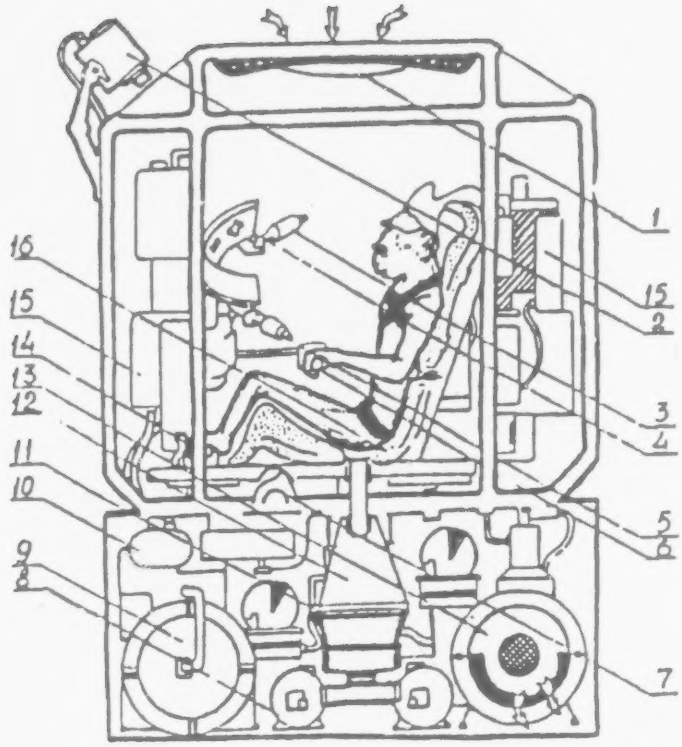
Organs:

12. Morphometric Studies of Atrial Granules and Hepatocytes
13. Morphological and Biochemical Examination of Heart Tissue
14. Hepatic Function in Rats After Space Flight
15. Morphological Examination of Rat Testes
16. Structural Changes and Cell Turnover in the Rat's Small Intestine Induced by Space Flight
17. Study of Muscarinic and GABA (benzodiazepine) Receptors in the Sensory-Motor Cortex, Hippocampus, and Spinal Cord
18. Pineal Physiology in Microgravity—Relation to Gonadal Function
19. Effect of Space Flight on Pituitary Oxytocin and Vasopressin Content
20. Effect of Microgravity on (1) Metabolic Enzymes of Type 1 and Type 2 Muscle Fibers and on (2) Metabolic Enzymes, Neurotransmitter Amino Acids, and Neurotransmitter Associated Enzymes in Motor and Somatosensory Cerebral Cortex
21. Growth Hormone Regulation, Synthesis, and Secretion in Microgravity
22. Effect of Space Flight on Levels and Function of Immune Cells

Other:

23. Radiation Dosimetry and Spectrometry Experiments
24. Primate Skeleton

Source: NASA Life Sciences Division.



Copyright: COSPAR

Figure 3.—BIOS Primate Capsule. Primate compartment used in Cosmos biosatellites. 1-light source, 2-TV camera, 3-food nozzle, 4-panel for light indicators, 5-juice nozzle, 6-stick for arm actograph, 7-device for chair swinging, 8-fans, 9-food container, 10-juice container, 11-activated charcoal filter, 12-waste.

(Source: Gazenko, O.G. and Eu.A. Ilyin. Investigations On-board the Biosatellite Cosmos–83. Advanced Space Research, 4(10), 1984, pp. 29–37.)

Cosmos 1667, two years later, was similar in many respects to its predecessor. However, there were some key differences. Now that confidence had been gained with the primate model, the cardiovascular and vestibular studies focused more closely on the responses during the acute phase of adaptation. The monkey experiment suite was a direct follow-on to the experiments that had been conducted on Cosmos 1514. However, the focus of the rat experiments shifted from embryology to a range of adaptation/readaptation studies. Responses at all biological levels were examined, including biochemical, morphological, and histochemical analyses, as well as studies of reproductive function in the (male) rats.[326]

Cosmos 1887, in 1987, again carried rats and monkeys, along with fish and insects; there was also a radiation dosimetry experiment. But this was a 14-day mission, twice as long as Cosmos 1667 had been. Now, with a longer adaptation period, the focus of interest in the rats shifted more toward bone and muscle studies. (See Table 17 above.) In the primates, there were now no cardiovascular studies. Instead, the focus was on musculoskeletal system and calcium metabolic studies, as well as the neurovestibular studies that had been a focus of the previous flights.[327]

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[326] Cosmos 1667. American Society for Gravitational and Space Biology Newsletter, 1(2), September 1985, pp. 2, 4.

According to a U.S. collaborator, the Soviets are not planning cardiovascular studies for the projected 1989 biosatellite mission involving primates.[328] It is possible that the Soviet decision to drop the primate cardiovascular studies indicates either (a) trouble with the implanted bioinstrumentation or (b) a realization that there are problems with the primate model for these studies. Such problems could include the fact that the small size of the monkey imposes a limitation on the size of the implants and instruments. Since there is a limit on the recording capacity of the satellite, eliminating the cardiovascular experiments makes it possible to do more in other fruitful areas (e.g., neurovestibular). It is true that the longer duration of the mission could be a factor. Skeletal effects of microgravity begin to be seen in monkeys in 14 days. (Rats require about a week, humans 1–2 months.) However, a complete list of Soviet experiments on Cosmos 1887 (which could shed light on this question) was unavailable at the time of writing.[329]

The Cosmos 1887 mission met with some mishaps. First, it was reported that one of the flight monkeys had managed to free his left arm from restraint on the fifth day in orbit.[330] Then the spacecraft overshot its planned landing point by some 2,000 miles, coming down in a Siberian forest.[331] Despite cold temperatures and a delayed recovery, all the "passengers" of the biosatellite except the guppies were reported to be in good condition. (The guppies, however, died.)[332] The rats were to have been removed and dissected immediately after landing, and the tissues rushed to Moscow for analysis by waiting teams of Soviet and foreign researchers. However, since about 24 hours elapsed before the spacecraft was reached and the specimens were removed, it is assumed that some experiments were slightly compromised.

## SUMMARY OF RESULTS

### *Overall Conclusions*

As a result of scores of experiments performed on both piloted and automated spacecraft, covering the biological spectrum from single-celled organisms and viruses to higher plants and animals, the Soviets have concluded that microgravity has few pathological or harmful effects on biological functions.[333] [334] Changes seen in animals are adaptive, and parallel those seen in humans. Table 18 summarizes the results of U.S. and Soviet biosatellite experiments.

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[327] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

[328] Ibid.

[329] Ibid.

[330] TASS, 1747, GMT, October 8, 1987.

[331] TASS, 0951 GMT, October 13, 1987.

[332] TASS, 1252 GMT, October 15, 1987.

[333] Dubinin, N.P. (Ed.). Biological Studies on the Salyut Orbiting Stations, op. cit.

[334] Gazenko, O.G. and Eu.A. Ilyin. Investigations On-board the Biosatellite Cosmos-83, op. cit.

An important overall conclusion is that, in higher plants and animals, gravity probably does not affect processes at the cellular level. It appears instead that, in microgravity, specialized systems designed to sense gravity in these higher organisms provide sensory input to other physiological systems that in turn produce the physiological or behavioral changes observed.[335]

### *Cells and Tissues*

The Soviets have concluded (as have most U.S. gravitational biologists) that microgravity has no significant effect on one-celled organisms. Indeed, they have reported that for many microorganisms growth seems to be slightly enhanced in space, compared with ground controls.[336]

TABLE 18.—SUMMARY OF RESULTS FROM COSMOS BIOSATELLITE EXPERIMENTS TO DATE

| | |
|---|---|
| Plants | Problems with orientation<br>Early development normal<br>Complete life cycle difficult (achieved only once) |
| Insects | Altered behavior and aging<br>Normal development<br>No significant mutations |
| Animals | Decreased bone growth and strength<br>Altered bone maturation<br>Increased RBC hemolysis and decreased RBC formation<br>Muscle atrophy, differential fiber changes, contractility<br>Altered behavior, balance, coordination<br>Altered liver enzymology<br>Altered body composition<br>Stress-associated changes<br>Altered vestibular system<br>Normal mammalian fetal development |
| Cells and tissues | No substantial changes in growth and reproduction<br>No significant mutations |
| Artificial gravity | Effective countermeasure to microgravity (Centrifugation) |

Source: NASA Life Sciences Division, 1986 unpublished material (derived from published U.S. and Soviet findings from Soviet biosatellite missions).

They have also concluded that there are apparently no genetic effects of weightlessness; nor does radiation encountered in near-Earth space appear to combine with microgravity to produce synergistic effects.[337]

### *Plants*

The Soviets have been very active in the study of plants in space. The ultimate goal here is to gain the knowledge needed to develop bioregenerative life support systems for use in space, with plants as a prime component; terrestrial agricultural biotechnology is perhaps a secondary (but related) focus. Therefore, a primary objective of Soviet plant biology has been the growth of plants from seed to seed. This objective, long sought, was finally achieved aboard Salyut 7 in 1982 when Arabidopsis plants grown from seeds in space were brought through a complete life cycle and produced fertile seeds.[338] However, this accomplishment has not been duplicated. Three types of plants—winter wheat, peas, and cotton—have been induced to sprout from seeds and grow aboard Soviet space stations. Plants such as peas and lettuce have even been harvested by the cosmonauts as food. Overall, however, the Soviets have experienced considerable difficulty in growing plants in space.[339] Many plants have grown normally for short periods but then slowed their growth and frequently died. Death often occurred at the flowering stage. Orchids brought onboard Salyut 6 immediately lost their flowers and would not flower in space, although they subsequently flowered on Earth. On Salyut 7, cotton seedlings died soon after they had begun to grow; only on the third attempt was this experiment successful.[340] Lack of gravity also disturbs the orientation of plants; gravity directs the orientation of root systems.[341]

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[335] Gazenko, O.G. and G.P. Parfenov. Third Decade of Space Biology. Kosmicheskaya Biol. i Aviak. Medit., 16(2), 1982, pp. 4-10.

[336] Parfenov, G.P. Biological Entities in Outer Space. Vestnik Academii Nauk SSR, 1982, pp. 71-80.

[337] Ibid.

Results of recent investigations indicate that microgravity has no effect on the generative stage of plant development or on the metabolism of germinating seeds.[342] [343]

### *Insects*

No significant physiological effects of space flight have been seen in insects (viz., fruit flies). Drosophila (fruit flies) have reproduced normally in space, and have lived through an entire life cycle under observation in space.[344]

### *Animals*

Using a variety of mammals, as well as tortoises and amphibians (newts), the Soviets have consistently demonstrated that space flight leads to generally reversible physiological changes comparable to those seen in humans, especially in the musculoskeletal and cardiovascular systems.[345]

In rats, no pathological changes were detected after biosatellite flights of 18–22 days duration; measured fluid-electrolyte changes were similar to those seen in humans, as were the changes in load-bearing muscles and bones. These changes returned to normal after a 25–27 day postflight recovery period. Fetal development and birth were generally normal. The adverse effects of exposure to gamma radiation (200 and 800 rad from Cs–137) were no different in microgravity. In monkeys, physiological changes recorded during the five-day flight of Cosmos 1514 involved the vestibular apparatus and the muscles, with no significant cardiovascular changes. In general, the health of both rats and monkeys on these flights was not affected by the experience.[346]

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[338] Merkys, A.J. and R.S. Laurinavichius. Complete Life Cycle of Individual Development of Arabidopsis thaliana (L) Heynh. Plants on Board the Salyut–7 Orbital Station. Dokl. Akad. Nauk SSSR, 271(2), 1983, pp. 509–512.

[339] Halstead, T.W. and F.R. Dutcher. Plants in Space. In (W.R. Briggs, et al., Eds.) Annual Review of Plant Physiology, 38, 1987, pp. 317–344.

[340] Pravda Vostoka, No. 167, July 22, 1987, p. 3.

[341] Halstead, T. W. and F. R. Dutcher. Plants in Space, op. cit.

[342] Gazenko, O.G. and Eu.A. Ilyin. Investigations On-board the Biosatellite Cosmos–83, op. cit.

[343] Tairbekov, M.G. and A.V. Deviatko. Energy Transfer in Plants in Weightlessness. Akad. Nauk SSSR, 280(2), 1985, pp. 509–512.

[344] Parfenov, G.P. Biological Entities in Outer Space, op. cit.

[345] Ilyin, Eu. A. and O.G. Gazenko. Problems in Gravitational Physiology and Their Solution in Cosmos Flights. The Physiologist, 27(6, Suppl.), 1984, pp. S–3—S–6.

[346] Ibid.

### *Artificial Gravity*

Unlike the United States, the Soviets have been pursuing a relatively large and comprehensive effort to study the use of artificial gravity to prevent or reduce the effects of microgravity. Applied to both plants and animals by means of centrifuges, of various sizes and rates of rotation, artificial gravity has been shown to be an effective countermeasure. In rats, centrifugation prevented bone demineralization and muscle mass loss and atrophy, while it normalized cardiac function, hormonal metabolism, and blood chemistry.[347]

### *Controlled Ecological Life Support*

Biologically closed, or regenerable, life support systems will probably be an essential feature of any piloted space mission lasting more than two years without resupply (e.g., perhaps an exploratory surface mission to Mars).[348] (NASA refers to such systems as "controlled ecological life support systems," or CELSS.) Such a system must regenerate water, oxygen, and food while recycling carbon dioxide and human and plant wastes. The scale of Soviet activities devoted to research on the extremely complex and diverse problems relating to development of such systems is quite impressive. Many Soviet laboratories and institutes are engaged in research on different aspects of the CELSS problem. Both ground-based and space-borne experiments are pursued.

Several different "space greenhouses" have been flown aboard the Salyut stations. Tended by cosmonauts, these small-scale systems have included a variety of algae and yeasts and such plants as dill, onions, peas, lettuce, ferns, and wheat. Housefly larvae have been included for disposal of human waste; and Japanese quail have been tested because of their high egg yield and rapid growth.[349] [350]

Since the substrate utilized for plant growth in such a system would consist largely of human wastes, contamination is a major potential problem. Much research is devoted to maintenance of the proper chemical and bacterial balance in CELSS systems.[351] In addition, spaceflight environmental factors add an extra dimension to the problems encountered in ground-based studies of CELSS.

Among the most interesting Soviet efforts in this area have been their ground-based "demonstrations" of CELSS technology. The Soviets have a full-scale human-rated CELSS demonstration system at Krasnoyarsk, Siberia, in which they have maintained 2–4 people for period of up to 6 months. This system is said to be about 80 percent "closed," meaning that about 20 percent of the required food is supplied from outside. Air, water, and the remaining food is cycled within the facility (which is roughly as large in volume as the U.S. Skylab space station). Special plant growth chambers within the facility can grow a variety of edible plants in a total planting area of about 60 $m^2$.[352]

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[347] Kotovskaya, A.R., et al. Artificial Gravity in Spaceflight. The Physiologist, *23*(6, Suppl.), 1980, pp. S-27—S-29.

[348] U.S. Congress. Soviet Space Programs: 1976–80, op. cit., p. 714.

[349] Shepelev, Ye.Ya. Biological Systems for Human Life Support. NASA TM-76018, 1979.

[350] Shepelev, Ye.YA., et al. Physiological and Ecological Characteristics of the Water Fern, Azolla Pinnata, and Prospects of Using It in Biological Life Support Systems for Man. Kosmicheskaya Biol. i Aviak. Medit., 17(5), pp. 66–69.

[351] Kovrov, B.G. and V.A. Kordyum, V.A. (Eds.). Microorganisms in Artificial Ecosystems. Novosibirsk, Nauka Press, 1985.

The U.S. space program is interested in CELSS technology, but has had little opportunity to pursue it in space for sufficient durations. However, NASA's Life Sciences Division now has a small CELSS program to support ground-based research. According to NASA biologists, the classic difference between the U.S. and Soviet approaches to CELSS is that the Soviets view it as, at best, an adjunct system playing a supporting role in long-term life support in space (e.g., the 80 percent closure of the Krasnoyarsk system). The U.S. approach is said to be to design for 100 percent closure. This is technically much more difficult to achieve.[353]

## SUMMARY AND CONCLUSIONS

### ONGOING TRENDS

Overall, the Soviets have a considerably larger effort in the space life sciences than does the United States. Not only do they conduct more experiments, but—more importantly—their program is more integrated. They focus all their efforts on a single long-term goal, unlimited human occupancy of space, so that overall program coordination and planning has a clear rationale. At the same time, with the relatively great range of flight options and opportunities they enjoy, the Soviets have the luxury of pursuing a broad-based approach to space life sciences research. Given a particular problem such as disuse atrophy of muscles, they can study the physiological effects, the mechanisms involved, physical countermeasures such as exercise, other countermeasures such as drugs, and methods of treatment. All these aspects can be investigated over the short or long term, inflight or on the ground, and in a variety of different organisms and models. With these advantages, it is less difficult to find answers to complex questions.

Primary emphasis in the Soviet program is still placed on microgravity effects and countermeasures. However, by U.S. standards they also have underway a large and long-term effort to study radiation biology, bioregenerative life support, and artificial gravity. The Soviets also place a relatively enormous emphasis on psychological/sociological effects and countermeasures relevant to long-duration space flight. These latter interests all point to a gradual building of momentum toward long-term interplanetary missions, such as to Mars.

### OUTLOOK FOR THE FUTURE

For the near term, it can be expected that the Soviets will continue their effort to extend the duration of flight by individual cosmonauts and crews to a year and beyond. (The duration of prior bedrest studies will be a useful predictor.) Continued extension of the duration and frequency of extravehicular activities is also likely. Permanent occupancy of Mir has begun with the transfer of operations from Soyuz TM-2/TM-3 to Soyuz TM-4.

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[352] Ivanov, B. and O. Zubareva. To Mars and Back Again on Board Bios. Soviet Life, 4, 1985, pp. 22–25.

[353] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

Biological research aboard Cosmos biosatellites can be expected to continue, with the next mission set to take place in 1989. The payload is likely to be very similar to that of the three that preceded it. It will include monkeys, and will probably emphasize musculoskeletal and neurovestibular studies.[354] Biomedical research activity planned for the Mir station includes a 30-day French-Soviet mission now scheduled for November 1988 which will feature cardiovascular, sensorimotor, and radioprotection research.[355]

Cosmonaut activity aboard Mir will accelerate in conjunction with physical expansion of the station. In particular, one of several modular additions planned for the station is a "dedicated biomedical space laboratory" known as Medilab.[356] Similar in size and specifications to Kvant, Medilab is currently in development. It will contain a broad range of scientific research equipment as well as computers to allow inflight data processing. The module will be used by specialists in both space medicine and biology to (1) monitor and maintain the health of space station personnel, (2) perform emergency medical and diagnostic procedures, (3) perform non-invasive studies on cosmonauts, and (4) conduct biological experiments on animals, tissues, and cells. As Mir crews become larger and perhaps more diverse, it is possible that a physician will be permanently "on call" aboard the station. (Medilab would facilitate the realization of that possibility.)

Going farther out in time it is easy to envision steady Soviet progress toward "major permanent orbital stations manned by thousands",[357] and toward lunar colonization and human exploration of Mars, all geared to steady advances in the life sciences across the broad front that is already smoothly in motion.

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[354] Sulzman, F., NASA Life Sciences Division. Personal communication, October 26, 1987.

[355] Braak, L., A.I. Grigor'yev, et al. Biomedical Payload of the French-Soviet Long Duration Flight. Technical publication, Centre National d'Etudes Spatiale, Paris, France, 1987.

[356] Gazenko, O.G., et al. Medilab—Design for a Medical Laboratory in Space. Presented at the 1987 NASA Life Sciences Symposium, Washington, DC, June 21–26, 1987. Abstracted in (L. Hooke et al., Eds.) USSR Space Life Sciences Digest, No. 13, September 1987, pp. 72–73.

[357] Academician Boris Paton, December 1986, quoted in Pesavento, P. Sputnik's Heirs, op. cit., pp. 34.

# CHAPTER 5—FUTURE PILOTED SPACE ACTIVITIES

The previous chapters have recounted the progress the Soviets have made in the area of piloted space flight, the knowledge they have gleaned about the reaction of the human organism to long durations in space flight conditions, and their activities in attempting to create closed cycle life support systems. The obvious question is what will be next in the Soviet piloted space program. The Soviets have near term objectives that include development of a reusable space shuttle and, apparently, long range goals such as human visits to Mars. Like their Western counterparts, however, Soviet space officials do not speak with a single tongue when prophesying about the future, and if they have an "official" set of long term goals for using crews in space, they have not been made public. Thus, discoursing about their future plans involves a certain amount of guess work and reading between the lines. Given these limitations, the following chapter attempts to lay out what those goals seem to be at the end of 1987.

## NEAR-TERM SPACE STATION ACTIVITIES

Although Mir has ushered in the era of permanently occupied Soviet space stations, the Soviets admit that they do not yet have a truly efficient operation resulting in products useful on Earth. Some of the problems stem from the amount of time the crews must spend on physical exercise and maintenance, while others involve the lack of opportunities to return the results of space experiments to waiting researchers on Earth, and the lengthy analysis they undergo once they are in the hands of scientists.

General Shatalov gave a candid interview to a Soviet journalist in October 1987 [1] in which he detailed some of the obstacles confronting them in using Earth orbital facilities efficiently:

> Two small cabins have been installed [on Mir] for the main crew. But to be honest, as yet cosmonauts' living conditions are more severe than, say, those on submarines. The new Soviet "Energiya" rocket, capable of putting into orbit stations with a mass of more than 100 tonnes, will further raise the quality of life in orbit and expand research capability.
>
> * * * * * * *
>
> No matter how much we mix the various elements of the daily program, both it and life on board remain quite monotonous. . . . In this atmosphere, the alternation of work and relaxation is very important. At the moment, relaxation on board the craft is the Achilles' heel of spaceflights. . . . As the stations are improved, so the opportunities for relaxation will also increase.
>
> But it is very important to switch from today's psychological crew support which, like it or not, is weak, to a permanent psychological contact between cosmonaut and earth. In my view, it is more important for the cosmonaut to be able to watch the "Vremya" program at its usual time than even the very best video recording. It is more important to be able to telephone home via the radio at any time rather than

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[1] Nedelya, October 12-18, 1987, pp. 7-9.

> wait for the special Sunday contacts with families. . . . I believe that we still attach insufficient attention to this matter.
>
> Generally speaking, I see not only the psychological backup but also the entire medical backup for the crew's normal activity as a great reserve. This is my personal opinion, and doctors may disagree with it. Cosmonauts have long been saying among themselves that, at the moment, our medical science is applying means of countering effects of weightlessness on too broad a front. . . . We find it surprising that regardless of how many men there are on board—two or three—they all make maximum use of resources offered by space medicine to maintain their ability to work in weightlessness and during reacclimatization. It would seem more sensible to let one cosmonaut use one method, let a second cosmonaut use another method, compare them, and draw conclusions. But no, everything is "lumped together," and it is impossible to separate the more effective from the less effective. . . . The exercises consume much work time. . . . [This may have been necessary in earlier times, but] crews are constantly on the move now, installing things and doing physical work. That fact must be taken into account. "Progress" spacecraft make regular visits. . . . And the unloading of the "cargo ships" and the loading of used equipment into them is difficult work. The cosmonauts themselves acknowledge that they become very tired. Still, they have to go on turning the pedals and running on the machine like guinea pigs. The sheer monotony of this is very tiring, but the main point is that the whole time there is the doubt as to whether so much physical exercise is necessary.

Concerning the results of the many experiments conducted on the space stations, he seemed less enthusiastic than might have been expected.

> Some areas, such as space photography, are yielding practical results. But in general, of course, there is a lack of purposefulness and consistency. There is, in my view, an unsystematic search going on, with a range of experiments in the most diverse areas. There is a lack of a good program with a precise formulation of goals and how to achieve them stage by stage. This is clearly in some part due to the general state of science in the country, which is poorly coordinated with the national economy and remote from practical needs. Nevertheless, much is being done at this moment in space that is capable of producing quite a considerable spin off for the national economy. But the crews will bring the results back to earth, and everything will then disappear "down a hole," as it were. But much could be changed if we did not have to wait for results of such experiments to be brought back to earth once every 6 months. . . . It also happens that we wait 6 months in space orbit. We carry out studies for 6–12 months on earth. Only then do we prepare the next experiment. At this pace we will not set up orbital workshops and factories, which the press has in fact promised many times over, even by the year 2000.
>
> . . . Perhaps we should adapt one of the modules [for Mir] as capsules, which would be periodically dispatched to earth with the results of the experiments.

Shatalov's remarks suggest that the Soviet research program may be proceeding at a slower rate than it is given credit for in the West, despite the more optimistic assessments quoted in the sections on "experiments" in Chapters 2 and 3 or scientist Leonid Leskov's comment that the production of semiconductor and electro-optical materials could give a profit of up to $200 million (U.S. dollars) per year.[2] The fact that the Soviets are in orbit with long duration missions already, learning about the operational difficulties involved in such activities, nevertheless gives them a considerable advantage in preparing for industrial space activities.

A specific problem not mentioned by Shatalov in performing materials processing experiments on space stations is the crew itself. Crew movements create gravitational influences that interfere with these sensitive experiments. In 1986, Prof. Sergey Grishin commented that this problem could be overcome by designing

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[2] Leskov, L. Power-Industry Orbital Complexes of the 21st Century. Space Policy, February 1985, p. 84.

"modules within modules" so that the walls of the inner module do not touch the outer module. In this manner, the outer module would protect the inner module and its experiments from external forces. The modules would fly independently of the space stations, and be serviced by the crews only occasionally.[3] It is possible that the Mir materials processing module will be of this design, accounting for the delay in its launch.

In early January 1988, the Soviets stated that Mir-2 was in development, and that, like Mir, it would be a modular station. The announcement said that it would be assembled "from a base block around which there will be metal frames for platforms carrying research equipment" and that "the giant parts for the future complex" would be launched by the large Energiya booster. No scheduled launch date (or year) was given.[4]

## SOVIET SPACE SHUTTLE AND SPACEPLANE

At the end of 1983, where the last version of this report left off, rumors in the West were rampant that the Soviets were developing their own version of a reusable space shuttle as well as a smaller "spaceplane." Conflicting statements had been made by the Soviets themselves about the existence of a shuttle program, and nothing had been said about the spaceplane. By the end of 1987, the Soviets had finally formally announced that they were developing a shuttle that would be launched by their Energiya launch vehicle.[5] At the end of 1987, they flew one of the cosmonauts in training for shuttle fights (Levchenko) on a week-long mission and then had him fly an airplane immediately after landing on Earth, apparently to determine whether weightlessness had affected his skills. The Soviets were not so open about their spaceplane program, however. On the occasion of the fourth orbital test of a prototype spaceplane in 1984, a Soviet official acknowledged that it was an experiment related to reusable spacecraft, but no further details have been forthcoming.[6]

### SPACE SHUTTLE

Drawings of the Soviet shuttle began appearing in editions of DOD's annual "Soviet Military Power" in 1983. It showed the vehicle mounted on the side of a very large launch vehicle (see figure 7), and as the years went by, the DOD illustrations and accompanying text made clear that it was very close in design to the U.S. space shuttle with one extremely important difference: the Soviet shuttle has no main engines for achieving orbit. Rather, the large launch vehicle, called Energiya, will be used for that task.

This design difference makes the Energiya/Shuttle a much more versatile system. Energiya is basically a heavy lift launch vehicle that can carry many different payloads into orbit—the shuttle is only one of them. With the U.S. shuttle, all elements of the system (the two solid rocket boosters, the external tank, and the orbiter) must fly into space each time. Thus, whatever payload is to be delivered into orbit must fit inside the cargo bay of the orbiter. The entire mass of the orbiter must be launched each time as well, diminishing the amount of payload mass that can be launched with it. In the Soviet design, if they have large payloads that cannot fit into the orbiter's payload bay, they can simply decide not to launch the orbiter at all.

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[3] NTR: Problemy i Resheniya, January 21-February 3, 1986, p. 8.

[4] Moscow World Service, 0800 GMT, January 6, 1988.

[5] Trud, April 7, 1987, p. 3; Pravda, May 14, 1987, p. 1.

[6] Boehlen, C. Soviets Say Shuttle Test Under Way. Washington Post, December 29, 1984, p. A10; Soviet Confirms Testing of Reusable Spacecraft, Aerospace Daily, January 2, 1985, p. 4.

Dimensions of the Soviet shuttle have not been made available by the Soviets, but a 1984 British article described it as 33 meters long with a fuselage diameter of 5.5 meters and a wingspan of 23 meters.[7] DOD estimates that the Soviet shuttle will be able to carry 30,000 kg of payload into orbit,[8] and Western reports have stated that two shuttle orbiters have been spotted by U.S. satellites.[9] In the 1987 edition of "Soviet Military Power," DOD asserts that "Soviet orbiter development has been heavily dependent on U.S. orbiter propulsion, computer, materials and airframe design technology. By using U.S. technology and designs, the Soviets were able to produce an orbiter years earlier, and at far less cost, than if they had depended solely on their own technology." [10] *Aviation Week and Space Technology* quoted an unnamed senior U.S. space official as complaining that "It is a travesty that the U.S. has not been able to maintain better control over the design and specifications about what had gone into our space shuttle to prevent benefit to the Soviets." [11] The article also stated that the Soviet Union saved "several hundred million dollars in research and development funding on its space shuttle program" because of "careless U.S. technology transfer practices." Since the article did not have a byline, and the official quoted was not named, it cannot be determined whether this position is widely held in the U.S. Government, or how the figure of "several hundred million dollars" was determined.

A disadvantage of the Soviet design is that the shuttle main engines apparently are not reusable since they are on Energiya and not the shuttle itself. The question of whether Energiya is reusable remained unclear at the end of 1987, because of conflicting Soviet information. At the Space Future Forum in Moscow in the first week of October, 1987, Soviet officials stated that Energiya was completely "recoverable," the implication being that it was also reusable.[12] Two weeks later at the International Astronautical Federation (IAF) meeting in Brighton, England, one of the Energiya designers emphatically stated that although they had considered building a reusable system, they had decided to make it expendable, at least for now.[13] Thus, the question remains open about Energiya's recoverability or reusability, but the likelihood that they would be able to recover the liquid hydrogen/liquid oxygen engines seems small since the flight profile takes that part of the vehicle over Siberia and the north Pacific.

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[7] Parfitt, J. New Soviet Space Vehicles. Spaceflight, November 1984, p. 410.

[8] U.S. Department of Defense. The Soviet Space Challenge. Washington, U.S. Govt. Print. Off., 1987, p. 14.

[9] Soviet Shuttle, Heavy Booster In Serious Development Trouble. Aviation Week and Space Technology, May 27, 1985, p. 21. In April 1983 an aircraft carrying one of the orbiters reportedly ran off the runway at Ramenskoye flight test center. (Aviation Week and Space Technology, April 18, 1983, p. 17.)

[10] U.S. Department of Defense. Soviet Military Power--1987. Washington, U.S. Govt. Print. Off., 1987, p. 54.

[11] Soviets Profit By Using U.S. Space Technology. Aviation Week and Space Technology, October 6, 1986, p. 23.

[12] Soviets Fly Jet-Powered Space Shuttle Testbed. Aviation Week and Space Technology, October 12, 1987, p. 24.

[13] Personal observation.

Also at the IAF meeting, Soviet officials stated that their prime interest in a space shuttle was not to take payloads into orbit, but rather to bring payloads back. They linked this return capability to the scientific modules that are planned for Mir. In fact, they stated that since the next module would not be ready for Mir until late 1988 or 1989, there was no rush to get their shuttle operating, and asserted that they were not in a race with the United States to see who would launch the next shuttle mission.[14]

When will they achieve their first shuttle launch? Obviously, only the Soviets know what their development schedule is, but one pacing item is the availability of Energiya. The first test of the system, in May 1987, failed. It is not likely that the Soviets will commit to placing a shuttle orbiter on Energiya until they have had several completely successful tests, and they said at the IAF meeting that they were still analyzing the data from the May test flight and would not launch Energiya again until sometime in 1988.[15] Another potential problem was mentioned in a Western press report following the Space Future Forum which asserted that the Soviets were having difficulties with the orbiter's digital flight control system.[16] Between the problems with Energiya and the difficulties with the orbiter systems, it seems unlikely that there will be a shuttle launch before 1989.

This does not mean they are not making progress in the shuttle program, however. In December 1986, *Aviation Week* reported that tests of the shuttle on its launch pad at Tyuratam had taken place and called it "a significant milestone toward first flight of the vehicle." [17] Almost a year later, *Aviation Week* identified Cosmonaut Igor Volk as chief pilot for the shuttle test program, and stated that orbiter tests were being conducted with runway take-offs, rather than having the orbiter dropped from an airplane as was done for flight tests of the U.S. space shuttle.[18] The report said that the flight testbed orbiter was equipped with "four 20,000-lb.-class Lyulka engines that provide sufficient thrust to power the vehicle through a conventional runway takeoff to an altitude from which it can simulate the approach and landing profiles it will fly when returning from orbit." [19] *Aviation Week* had previously reported that the orbiter tests were conducted by dropping the orbiter from a Bison aircraft in much the same way the U.S. orbiter was tested in 1977.[20] It is not clear whether the test profile has changed, whether both methods are used, or whether the first report was incorrect.

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[14] Personal observation.

[15] Personal observation.

[16] Soviets Fly Jet-Powered Space Shuttle Testbed, op. cit., p. 22.

[17] Soviet Shuttle. Aviation Week and Space Technology, December 1, 1986, p. 29.

[18] Soviets Fly Jet-Powered Space Shuttle Testbed, op. cit.

[19] Ibid.

[20] Covault, C. Soviets Begin Orbiter Tests Following Engine Installation. Aviation Week and Space Technology, April 14, 1986, pp. 16–18.

*Aviation Week* has also reported that the Soviet shuttle will be equipped with jet engines to provide more flexibility in landing, but these presumably would be different from those used for the test program. The U.S. shuttle has no power during landings, and therefore no ability to abort a landing once descent from orbit begins.[21]

Another question is whether a crew will be carried on the first shuttle flight, or if the test will be conducted with automated equipment. The United States departed from past practice and had a two-man crew aboard its first shuttle flight, so many Western observers have assumed that the Soviets would also put a crew aboard the first test of their shuttle. The Soviets, however, have consistently demonstrated an extremely conservative approach towards introducing new technology into their space program, and it would be quite uncharacteristic for them to test the shuttle with a crew. Even modifications to the Soyuz spacecraft (when it was upgraded to Soyuz T and later to Soyuz TM) were tested in an automated mode first. It seems highly unlikely that the Soviets would abandon this cautious approach, especially when moving to a completely new vehicle like the shuttle.

In its October 1987 article on the Soviet shuttle, *Aviation Week* reported that the first flight would be fully automated, but that it was "opposed by members of the Soviet cosmonaut corps . . ." and the possibility that the digital flight control system would not be ready in time left open the possibility of having a crew aboard.[22] The magazine went on to say that the cosmonauts were also opposed to Soviet plans to use automatic approach and landing systems for operational shuttle missions.

The Soviets took another step toward the first shuttle flight in December 1987 with the flight of Cosmonaut Anatoliy Levchenko on Soyuz TM-4. They announced that Levchenko's mission was related to the shuttle development program, and after he landed (with Romanenko and Aleksandrov from the Soyuz TM-2/TM-3 flight) he was immediately taken to fly an airplane, probably in an attempt to gauge the effect of a week in weightlessness on his piloting skills. The Soviets announced that he had passed the test "with flying colors." [23]

## SPACEPLANE

On December 19, 1984, the fourth orbital test of a sub-scale prototype spaceplane was conducted (Cosmos 1614).[24] Like the third in the series in December 1983, it made one orbit and landed in the Black Sea. DOD asserts that as many as 12 tests of the spaceplane have taken place; presumably the others have been suborbital.[25]

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[21] Soviets Fly . . ., op. cit.

[22] Ibid.

[23] Moscow World Service, 1500 GMT, December 24, 1987; Moscow Television Service, 1800 GMT, December 29, 1987; Moscow Domestic Service, 1835 GMT, December 30, 1987.

[24] Soviets Fly Fourth Orbital Test of Spaceplane Vehicle. Aviation Week and Space Technology, January 7, 1985, p. 19.

[25] Pentagon Reviews Data on Soviet Spaceplane Test. Aviation Week and Space Technology, August 31, 1987, p. 27.; Covert Boosters? Aviation Week and Space Technology, November 30, 1987, p 15.

DOD published illustrations of the spaceplane beginning in its 1984 edition of Soviet Military Power (photographs of the subscale prototype spaceplane from the March 1983 test flight have been made available by the Australians and an illustration appears in the last edition of this report).

The exact nature of the spaceplane program remains unclear. While DOD states that the spaceplane and space shuttle programs are separate, it is not readily apparent how both would fit into the Soviet space program. It is possible that the spaceplane is part of the developmental space shuttle program to test aerodynamics and materials, and will not be pursued as a separate vehicle. It is just as likely that it will be a space vehicle itself in the future, used for ferrying crews to space facilities or for military sortie missions. DOD asserts that the spaceplane could be used for "quick- reaction, real time reconnaissance missions, satellite repairs and maintenance, crew transport, space station defense, satellite inspection and, if necessary, satellite negation." [26] Any of these missions is a possibility, although offensive or defensive space weapons roles seem less likely since the Soviets would probably be reluctant to risk crew safety when, according to DOD, they already have an operational co-orbital antisatellite system using automated spacecraft.[27]

DOD assumes that the spaceplane will ultimately be launched by the new medium lift launch vehicle "J" (see next part of the report).[28] Despite a March 1987 claim by *Aviation Week* that the Soviets would "begin full-scale manned flight testing soon," [29] no such test had occurred by the end of 1987 and did not appear to be in the offing. DOD says only that a "possible full-scale version could be in production" and that "Testing of a full-scale space plane . . . could begin in the next few years." [30] The DOD report makes no mention of crews being aboard the test flights.

## MISSIONS TO THE MOON AND MARS

The Soviets have said very little about plans to send crews to the Moon since the 1960s when the United States won the Moon Race. In recent years, they have instead focussed on the potential for sending humans to Mars, and have made it clear that their long duration missions aboard space stations are designed to provide data relevant to such an undertaking.

### THE MOON

The lack of Soviet comments about human trips to the Moon during the 1970s led some Western analysts to conclude that the Soviets had lost interest in that goal. Even in the 1980s some Soviets are clearly less than enthusiastic. In 1984, for example, Soviet cosmonaut Konstantin Feoktistov asserted that there is no need to "do in space what has already been done by others when there is an enormous number of other unresolved problems."[31] Scientist Leonid Leskov, after assessing the prospects for solar power satellites as unrealistic in the near term (see below), added that proposals to begin industrial use of the Moon "should be regarded today as unfeasible too."[32]

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[26] The Soviet Space Challenge, op. cit., p. 13.

[27] Ibid., p. 11.

[28] The Soviet Space Challenge, op. cit., p. 14.

[29] Covault, C. Soviets Near Flight Test of Small Manned Spaceplane. Aviation Week and Space Technology, March 30, 1987, p. 23.

[30] Ibid., p. 13.

In November 1986, however, the views of scientist Vladislav Shevchenko began appearing in the Soviet press. In an article written for the Soviet Academy of Sciences and reported by TASS and other Soviet media, he discussed the possibility of establishing bases on the Moon and of using lunar materials (specifically aluminum, iron and titanium) to build large structures in Earth orbit. He also noted the advantages of putting astronomical facilities on the Moon, and stressed that international cooperation in establishing a lunar base could reduce costs to an individual nation.

Shevchenko described a novel approach to generating power on the lunar surface using a thermocouple that could take advantage of the 500 degree C difference between the light and dark parts of the Moon to generate power. Shevchenko reportedly suggested the year 2007 as a target date for establishing a lunar base, and proposed the western region of Oceanus Procellarum as the general location. The exact location would be determined by automated probes in the 1990s which would provide engineering data, followed by a human expedition by a crew of four (plus two rover vehicles) who would spend 30 days on the lunar surface and choose the final location. Once the site was selected, automated spacecraft would deliver the necessary materials, and then construction crews and researchers would be landed. Shevchenko estimated that eight flights would be needed to deliver the materials and the ninth flight would bring the first permanent crew to the base.[33]

The most compelling argument for Soviet trips to the Moon is based on the extremely conservative nature of the Soviet piloted space program. They still test even relatively minor modifications to their piloted spacecraft in an automated mode before approving them for use by crews, so a new spacecraft to journey to Mars would also have to be tested. Since the journey to Mars is so long, they might settle for testing it at the Moon instead. If they are planning a mission to circle Mars, but not land, a circumlunar flight might be sufficient. If they are planning to land crews on Mars, a landing on the Moon could be expected first. Based on past practices in the Soviet program, it is extremely difficult to imagine them sending crews to Mars without first testing the spacecraft closer to home.

At the end of Romanenko's 326 day mission in 1987, Gen. Shatalov directly coupled the concepts of a Mars mission and a lunar base. He suggested that cosmonauts returning from Mars might need to spend time on the Moon to begin readapting to gravity after their interplanetary journey in weightlessness. "There perhaps, the crew would have to spend some time, perhaps a month, in order to get used to, let us say, one-sixth of Earth's gravity." [34]

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[31] Sotsialisticheskaya Industriya, November 21, 1984, p. 4.

[32] Leskov, L. Power-Industry Orbital Complexes of the 21st Century. Space Policy, February 1985, p. 85.

[33] TASS, 1252 GMT, November 10, 1986, which summarizes Shevchenko's article in the October 1986 Bulletin of the USSR Academy of Sciences. The Bulletin article plus another in Sotsialisticheskaya Industriya (January 29, 1987) are abstracted in: Science and Technology Perspectives, Foreign Broadcast Information Service, April 8, 1987.

Shevchenko's arguments in favor of a lunar base are virtually identical to those expounded five months earlier in the May 1986 report "Pioneering the Space Frontier" by the U.S. National Commission on Space.[35] Shevchenko's time frame of 2007 (the 50th anniversary of Sputnik) for the first permanent crew to the Moon is only two years different from the Commission's recommendation of 2005. Both recommend international cooperation in such an endeavor.

### MARS

It is the possibility of sending people to Mars, however, that has attracted the most attention in recent years. The Soviets have made no secret of their desire to accomplish such a goal; after the 237 day mission in 1984 by the Soyuz T-10/T-11 crew, the Soviets stated: "They spent 237 days in weightlessness. This is precisely the time which an outer space craft needs to reach Mars with the modern level of technology." [36] The theme was echoed at the end of Romanenko's 326 day flight in 1987. Romanenko himself said at a post flight press conference that "For us, Mars is getting nearer and nearer to Earth, and this is like the latest step." [37] As their replacements, Titov and Manarov, began their mission on Mir at the end of 1987, deputy flight director Blagov said the mission, expected to last a year, was a "small step to a manned flight to Mars." [38]

Although there has been much speculation in the West about when they might send a crew to Mars, the Soviets themselves generally are cautious in setting a target date. Dr. Roald Sagdayev, head of the Soviet Institute for Space Research and a strong proponent of such a mission, was careful to hedge his remarks through the early 1980s, but in a December 1987 Washington *Post* editorial finally announced that his "sentimental goal" would be a landing on Mars by 2001, but that a more realistic goal might be 2005.[39] One of his colleagues, Irina Yegorova, had previously written that investigations by automated spacecraft would create "favorable conditions by the year 2020" for sending crews.[40]

Perspectives from the people who would fly such a mission have been provided by Cosmonaut Feoktistov and General Shatalov. Feoktistov said in 1984 that such a mission would not begin for at least 10-15 years, "but if there is a need to fly to Mars, the preparation for this flight will perhaps occupy less than 10 years" and that one impetus would be if life were detected using automated probes.[41] General Shatalov commented in October 1987 that "A flight to Mars and back will take 2–3 years. This is quite a different matter [from long duration missions in Earth orbit.] Right now, no one dares to say whether it is possible from the medical viewpoint without utilizing technical means simulating the earth's gravity.[42]

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[34] Moscow Domestic Service, 1430 GMT, December 20, 1987.

[35] U.S. National Commission on Space. Pioneering the Space Frontier. New York, Bantam Books, 1986.

[36] TASS, 1441 GMT, October 18, 1984.

[37] Moscow Domestic Service, 1835 GMT, December 30, 1987.

[38] Moscow World Service, 1500 GMT, December 24, 1987.

[39] Sagdayev, R. To Mars Together—A Soviet Proposal. Washington Post, December 13, 1987, p. M1-2.

[40] Moscow in Serbo-Croatian to Yugoslavia, 2000 GMT, March 10, 1987 (in FBIS, March 17, 1987).

[41] Sotsialistcheskaya Industriya, November 21, 1984, p. 4.

In fact, it seems that it is Western sources, rather than the Soviets, who insist that the Soviets are planning to go to Mars earlier than the turn of the century. Former U.S. astronaut and Senator Harrison "Jack" Schmitt predicted in 1984 that the Soviets would send a crew to "the vicinity of Mars" by October 1992, the 75th anniversary of the Bolshevik Revolution.[43] This theme was echoed in the 1985 edition of "Soviet Military Power," in which DOD asserted that the Soviets were "considering" a piloted trip to Mars in 1992.[44] This was toned down by 1987, when DOD stated that the Energiya booster would give the Soviets the capability to send crews to Mars and such a mission could be mounted in the first decade of the 21st century. DOD added, however, that a "non-stop fly-by mission to Mars [could take place] before the end of this century." [45] This question of whether the Soviets would send a crew to fly around but not land on Mars has been raised by others in the West. The value of sending a crew to that distance without actually landing on Mars, either in political or scientific terms, is questionable, and some Western observers argue that such a mission would be a waste.[46]

Where do the Soviets stand in terms of being able to send crews to Mars? In an unpublished analysis of what technological steps the Soviets must make before sending a mission to Mars, Soviet space analyst Nicholas Johnson concluded that the Soviets are far from having the ability to accomplish such a mission before the turn of the century.[47] He identified seven technological areas where improvements need to be made: reliable, long term propulsion; near continuous communications; on-board data processing; power generation and storage; semi-autonomous control systems; life support redundancy and alternatives; and decontamination. Johnson's assessment was that the Soviets do not now possess the technologies needed to undertake a human mission to Mars within this century, but they are conducting a technology assessment program to identify and develop those technologies, and data collected during the next ten years via robot explorers to Mars and on Earth-orbiting space stations will be fed into the Mars program. He concluded that although preliminary designs may be drafted in the early 1990s for a flight after the year 2000, a commitment to a flight schedule has not yet been made.

As noted in Chapter 4, the Soviets also have more to learn about the psychological and physiological aspects of such a long journey.

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[42] Nedelya, October 12–18, 1987, pp. 7–9.

[43] Schmitt Predicts Manned Soviet Flight to Mars by '92. Defense Daily, October 31, 1984, p. 317.

[44] U.S. Department od Defense. Soviet Military power—1985. Washington, U.S. Govt. Print. Off., 1985, p. 58.

[45] U.S. Department of Defense. Soviet Military Power—1987. Washington, U.S. Govt. Print. Off., 1987. p. 58.

[46] Covault, C. Soviets in Houston Reveal New Lunar, Mars, Asteroid Flights. Aviation Week and Space Technology, April 1, 1985, p. 19.

[47] Johnson, N. Speech to the Case for Mars III conference, Boulder, Colorado, July 1987.

While they are developing the data base from which to decide how and when to send people on very long missions, beyond the protective shield of Earth's atmosphere and magnetosphere, it does not appear that they have all the answers yet.

The possibility of a joint U.S/Soviet trip to Mars has peaked the interest of many space program observers in both countries. The Soviets have said that they are interested in cooperating with other countries in a Mars mission. Academician Avduyevskiy cited the success of the Apollo-Soyuz Test Project, adding that "Preparations for [a joint Mars] mission could even begin tomorrow." [48] Sagdayev went so far as to say that this type of mission "would not be realistic without international cooperation, and such an effort may be opened to the world's other space powers." [49]

Eminent U.S. scientists like Carl Sagan have suggested that a joint U.S./Soviet mission to Mars be mounted as an alternative to the U.S. Strategic Defense Initiative (SDI, or Star Wars) program.[50] Some Western analysts regret the linkage between SDI and a joint mission to Mars because it raises the possibility that if the SDI program disappears when a new President takes office that the Mars mission might lose impetus. There also is no historical basis for assuming linkage between cooperation in civilian space activities and the conduct of military space programs.[51] Nevertheless, Sagan's argument has given considerable visibility to the Mars proposal. The possibility of including other countries has been supported by the Planetary Society, a space interest group in the United States of which Sagan is President and Sagdayev is a Board member.

Obviously one concern on the part of some U.S. Government officials is the technology transfer that would almost certainly be involved in such a joint mission. Another problem is the rapidity with which relations between the superpowers warm and cool. The trip time to Mars alone would be more than a year (perhaps two-three years depending on the alignment of the planets when the mission is launched). A decade might be required to design and develop the spacecraft in the first place. There has not been a period of time since World War II when relations between the United States and Soviet Union have remained stable for such a long period. That is not to say that a joint mission is impossible, but the problems should not be understated. Michael Michaud, Director of the Office of Advanced Technology at the U.S. State Department, has noted that: "History clearly shows that cooperative efforts between the superpowers have been subject to ups and downs as the state of relations improved or deteriorated. There is no evidence to suggest that this will change in the future. The state of political relations will come first, and space cooperation will be a distant second in terms of priorities on both sides. . . ." [52] Michaud argues that the United States should mount a mission to Mars with friends and allies instead of the Soviet Union, pointing out that "Improving U.S.-Soviet relations is perfectly valid as a political agenda, but it is not a space agenda. Conversely, getting humans to Mars is a perfectly legitimate space agenda, but we can do it without the Soviets on board."

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[48] Trud, April 12, 1985, p. 2.

[49] Quoted in: Lenorovitz, J. Soviets Urge International Effort Leading to Manned Mars Mission. Aviation Week and Space Technology, March 24, 1986, p. 76.

[50] Testimony to the Senate Foreign Relations Committee. East-West Cooperation in Outer Space. Hearing held September 13, 1984. Washington, U.S. Govt. Print. Off., 1984.

[51] Smith, M. Space Cooperation Between the United States and the Soviet Union. Paper presented to the International Institute of Space Law, Brighton, England, October 1987.

[52] Michaud, M. Lets Go To Mars—With Our Friends and Allies. Paper presented at the Case for Mars III conference, Boulder, Colorado, July 1987.

The U.S. Congress has shown interest in the possibility of U.S./Soviet missions to Mars, both with automated spacecraft and crews. The Senate Foreign Relations Committee held hearings in September, 1984 on U.S./Soviet cooperation, including sending crews to Mars. In 1987, Representative Robert Roe, chairman of the House Committee on Science, Space and Technology, and Representative Manuel Lujan, ranking minority member of the committee, wrote to President Reagan asking that he raise the possibility at the December 1987 summit with Soviet General Secretary Gorbachev.[53]

The promise of improved superpower relations implied by announcing space cooperation on such a grand scale has caught the attention of many people, especially at a time when the two countries appear to be breaking new ground on arms control. Whether the idea of working together over a decade or more to cooperatively send the first representatives of Planet Earth to Mars is too bold, or just bold enough, remains to be seen. Perhaps a portent was contained in the speech by Soviet General Secretary Gorbachev after signing the Intermediate Nuclear Forces (INF) treaty at the December 1987 summit when he said: "People want to live in a world in which American and Soviet spacecraft would come together for docking and joint voyages, not for "Star Wars." [54] Sagdayev later clarified that the General Secretary did indeed mean trips to Mars.[55]

## OTHER FUTURE PROSPECTS

Soviet specialists, like their Western counterparts, have other proposals for future space activities. Some that have been discussed during the past four years are described below.

### SPACE REFLECTORS

Space reflectors, or mirrors, have been promoted by some Soviet scientists as a means of lighting parts of the Soviet Union during long winter nights to improve agricultural productivity, reduce electric consumption required for lighting cities, light fields to combat night frosts, and light areas where work must be conducted at night.[56]

An April 9, 1984, TASS reported on a proposal by the Moscow Institute of Aviation to launch 200 kg satellite-reflectors with a working area of 100 square meters, which would result in "luminance at a ground receiver with a diameter of 10 km" that would be "seven times more intense than during the full moon period at night (about 1.5 lux)."[57] The report noted that environmental studies were being conducted on the possible effects of such a system.

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[53] Letter to President Reagan from Representatives Roe and Lujan, November 18, 1987.

[54] Quoted in the Washington Post, December 9, 1987, p A29.

[55] Quoted in: U.S. Would Study Many Planets, Soviets Mars: NASA Official. Aerospace Daily, December 11, 1987, p. 378.

[56] TASS, 0638 GMT, April 9, 1984.

A Moscow World Service report several months later quoted Professor Arturov as explaining the benefits of orbiting mirrors, as well as the technical difficulties in creating them.[58] Lightweight space structures that require a minimum of assembly and an effective control system are two hurdles to overcome. He explained that the mirror would open like an umbrella once on orbit, and that the light reflecting surface would be metallized polymer film.

An article in February 1985 provided more details about the concept.[59] The reflectors would be in an orbit inclined at 92 degrees with an orbital period of 1.5 hours. A "caravan" of reflectors passing in sequence would be needed. This article also envisioned using similar reflectors for relaying electricity generated by solar power satellites to other space facilities (not to Earth), and for retransmitting laser communications signals.

Another report at the same time by Soviet scientist Leonid Leskov went even further. Estimating that an illumination level of about 10 luxes or about 100 full moons would be needed, Leskov concluded that a reflector with an area of several square km and a mass not more than 1,000 tonnes would be required to illuminate 90,000 square km. "Calculations show that the use of the system of reflectors with an overall area of 200 to 1,000 square km will make it possible to intensify considerably the production of cereals in middle latitudes on an area of up to 10 million hectares. Placing a system of reflectors with an overall area of 1,000 square km in an orbit 1,600 km high, it is possible to illuminate an area of about 200 square km on the Earth's surface at the level of full sun. Even with the use of modern photoelectric transducers this can ensure an electric capacity of up to 20 million kW. Besides, it is rational to use extra heat for obtaining hydrogen."[60]

## SOLAR POWER SATELLITES

Separate from the possibility of night illumination using space reflectors is the concept of using large solar arrays to generate electricity for transmission to other space facilities or to Earth. The space-to-Earth power applications have been promoted primarily by Peter Glaser of Arthur D. Little Inc. in the United States, but the Soviets have shown interest as well. First, however, they seem intrigued with the possibility of space-to-space power. At the time of the first Energiya launch in May 1987, for example, Guriy Marchuk, President of the Soviet Academy of Sciences, listed potential uses for the heavy lift launch vehicle including the placement in orbit of solar power satellites for providing electricity to space facilities.[61]

Cosmonaut Feoktistov discussed the possibility of space-to-Earth transmission in 1985. He proposed constructing a solar panel 100 square km in area from units measuring 100x100 meters. The facility would generate 10 gigawatts which would be beamed to receiving antennas several km in diameter on Earth. He estimated the mass of such a facility to be 50,000–100,000 tons, and that if a launch vehicle capable of taking 500 tons into orbit was available, it would take 100–200 trips over a period of three to five years.[62]

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[57] TASS, 0638 GMT, April 9, 1984.

[58] Moscow World Service, 0931 GMT, October 15, 1984.

[59] NTR: Problemy i Resheniya, February 19, 1985, p. 6.

[60] Leskov, L. Power-Industry Orbital Complexes of the 21st Century. Space Policy, February 1985, pp. 84-85.

[61] TASS, 0150 GMT, May 22, 1987.

An article in *Space Policy* by Leonid Leskov at about the same time portrayed the potential solar power satellites in less optimistic terms. He said that "Some experts believe that during the first decades of the 21st century such stations will already be the main power source for the Earth. However, this opinion is subject to serious objections." He set up the scenario of attempting to meet 20 percent of the world's power requirements by solar power satellites by the year 2020. If the implementation were to begin before the year 2000, he argued, it would be necessary to put 200,000 to 500,000 tons of cargo into low Earth orbit every week and that rockets capable of lifting 500 tons at a time would have to be launched every 20 minutes. At a cost of $20/kg (100 times less than the U.S. space shuttle), the launch costs alone would be $600 billion/year, according to his calculations. He also cautioned that the launch vehicles would leave up to 500,000,000 tons of combustion products in the atmosphere. "In other words, designs of a full-scale network of space-based power stations, which are being put forward at present, cannot be regarded as realistic." [63]

Nevertheless, Leskov did not reject the notion of solar power satellites entirely, recommending only that they evolve from smaller facilities, starting with a 1 MW unit. He cited Soviet research showing that the use of amorphous silicon, applied on a flexible film base, would reduce the specific mass of solar power satellites by up to 3-5 kg/kW. He also asserted that use of thermonuclear reactors is a promising possibility for this application.[64]

## FLIGHT CONTROL CENTER IN SPACE

Academician Avduyevskiy predicted that someday the Flight Control Center that tracks and communicates with spacecraft, complete with staff, would be located in space because of the increasing number of spacecraft. "Equipped with sophisticated computer technology, it will regulate the work of all automatic craft which are in orbit. Such an autonomous space complex, assuredly, must possess its own means for navigation, for calculating ballistic data, for obtaining energy, and it must have a device for making many trips to Earth and replacing specialists." [65]

## TRIPS TO JUPITER'S MOONS

In a 1984 article, Cosmonaut Feoktistov expressed interest in sending people to Jupiter.[66] Noting that Jupiter is scientifically fascinating, but that one cannot land on the planet itself, he suggested landing on one or more of its moons. "Satellites of Jupiter are a different matter: there is a large selection of them—at different distances from the surface of the planet, different dimensions and accordingly with different gravitation. And one would like to be on them." He ends this statement with the question "But will this occur in the foreseeable future?" One imagines that the answer depends on how long "foreseeable" is!

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[62] Knizhoye Obozreniya, April 12, 1985, p.6. Excerpt from his book "Seven Steps to the Sky."

[63] Leskov, L. Power-Industry Orbital Complexes of the 21st Century. Space Policy, February 1985, pp. 84–85.

[64] Ibid.

[65] Literaturnaya Gazeta, April 11, 1984, p. 10.

[66] Sotsialisticheskaya Industriya, November 21, 1984, p. 4.

### SPACE COLONIES

Feoktistov also expounded on the rationale behind placing colonies in space set forth by the father of Soviet rocketry, Konstantin Tsiolkovsky, and more recently by Gerard O'Neill in the United States. Feoktistov concludes that conditions have changed so much since Tsiolkovsky's time that there is no longer a compelling need to think about moving civilizations into space colonies. He sees O'Neill's arguments as an unwillingness to deal with the problems we face: "This is reminiscent of the hopes of . . . people who are incapable of keeping order in their own home but dream of doing it in a new apartment." He asserts that someday there will be large space objects for scientific and applied research "But they will hardly ever become the basic place and means for the development of terrestrial civilization." [67]

## CONCLUSION

The Soviets are well positioned to make plans regarding long range goals in using crews in space. How far they have proceeded in developing actual plans, with timetables and budgets, cannot be determined. While the Soviets have recently released lists of programs they plan to carry out through the end of the century in their automated space science program (see Volume 2 of this report), they are not as forthcoming with plans for their piloted space program. It may well be that such plans have not been approved yet.

The Soviets are, however, establishing the basic data base they need to decide about sending crews to Mars, for example, as well as for expanding their operations in Earth orbit. Speculating about what the next major step will be in the Soviet program is relatively easy—the launch of the space shuttle. Beyond that, however, only the Soviets know their plans.

TABLE 19.—COMPARATIVE DATA ON ASTRONAUT AND COSMONAUT CUMULATIVE TIME IN SPACE

| Name | Country | Number of flights | Cumulative time (hrs:min) |
|---|---|---|---|
| Romanenko | U.S.S.R | 3 | [1] 10,338:21 |
| Kizim | U.S.S.R | 3 | 8,993:59 |
| Solovyev | U.S.S.R | 2 | 8,686:51 |
| Ryumin | U.S.S.R | 3 | 8,685:34 |
| Lyakhov | U.S.S.R | 2 | 7,786:22 |
| Aleksandrov | U.S.S.R | 2 | 7,433:03 |
| Savinykh | U.S.S.R | 2 | 5,830:29 |

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[67] Sotsialisticheskaya Industriya, November 23, 1984, p. 4.

## TABLE 19.—COMPARATIVE DATA ON ASTRONAUT AND COSMONAUT CUMULATIVE TIME IN SPACE—Continued

| Name | Country | Number of flights | Cumulative time (hrs:min) |
|---|---|---|---|
| Atkov | U.S.S.R | 1 | 5,686:50 |
| Lebedev | U.S.S.R | 2 | 5,262:00 |
| Kovalenok | U.S.S.R | 3 | 5,194:12 |
| Berezovoy | U.S.S.R | 1 | 5,073:05 |
| Popov | U.S.S.R | 3 | 4,814:55 |
| Laveikin | U.S.S.R | 1 | 4,179:26 |
| Ivanchenkov | U.S.S.R | 2 | 3,540:39 |
| Dzhanibekov | U.S.S.R | 5 | 3,495:59 |
| Grechko | U.S.S.R | 3 | 3,236:33 |
| Carr | United States | 1 | 2,017:16 |
| Gibson, E. | United States | 1 | 2,017:16 |
| Pogue | United States | 1 | 2,017:16 |
| Sevast'yanov | U.S.S.R | 2 | 1,936:19 |
| Klimuk | U.S.S.R | 3 | 1,890:19 |
| Garriott | United States | 2 | 1,674:56 |
| Bean | United States | 2 | 1,671:45 |
| Lousma | United States | 2 | 1,619:14 |
| Vasyutin | U.S.S.R | 1 | 1,557:52 |
| Volkov, A. | U.S.S.R | 1 | 1,557:52 |
| Volynov | U.S.S.R | 2 | 1,255:20 |
| Zholobov | U.S.S.R | 1 | 1,182:24 |
| Conrad | United States | 4 | 1,179:38 |
| Gubarev | U.S.S.R | 2 | 899:37 |
| Young | United States | 6 | 835:42 |
| Weitz | United States | 2 | 793:14 |
| Gorbatko | U.S.S.R | 3 | 732:46 |
| Lovell | United States | 4 | 715:06 |
| Volkov, V. | U.S.S.R | 2 | 689:03 |
| Kerwin | United States | 1 | 672:50 |
| Dobrovolskiy | U.S.S.R | 1 | 570:22 |
| Patsayev | U.S.S.R | 1 | 570:22 |
| Cernan | United States | 3 | 566:16 |
| Crippen | United States | 4 | 565:49 |
| Scott | United States | 3 | 546:54 |
| Strekalov | U.S.S.R | 3 | 545:07 |
| Brand | United States | 3 | 530:58 |
| Nikolayev | U.S.S.R | 2 | 519:24 |
| Mattingly | United States | 3 | 508:34 |
| Stafford | United States | 4 | 507:43 |
| Bykovskiy | U.S.S.R | 3 | 497:49 |
| Makarov | U.S.S.R | 4 | 497:43 |
| Hartsfield | United States | 3 | 482:51 |
| Walker, C. | United States | 3 | 477:56 |
| Borman | United States | 2 | 477:36 |
| Savitskaya | U.S.S.R | 2 | 473:06 |
| Kubasov | U.S.S.R | 3 | 449:59 |
| Popovich | U.S.S.R | 2 | 448:29 |
| Glazkov | U.S.S.R | 1 | 425:23 |
| Shaw | Unitedf States | 2 | 412:51 |
| Bobko | United States | 3 | 386:04 |
| Fullerton | United States | 2 | 382:51 |
| Artyukhin | U.S.S.R | 1 | 377:30 |
| Ride | United States | 2 | 343:48 |
| McDivitt | United States | 2 | 338:57 |
| Nagel | United States | 2 | 338:23 |
| van Hoften | United States | 2 | 337:58 |
| Hauck | United States | 2 | 337:09 |
| Gardner, D. | United States | 2 | 336:54 |
| Gibson, R. | United States | 2 | 334:20 |
| Fabian | United States | 2 | 316:03 |

## TABLE 19.—COMPARATIVE DATA ON ASTRONAUT AND COSMONAUT CUMULATIVE TIME IN SPACE—Continued

| Name | Country | Number of flights | Cumulative time (hrs:min) |
|---|---|---|---|
| Gordon | United States | 2 | 315:53 |
| Brandenstein | United States | 2 | 314:48 |
| Thagard | United States | 2 | 314:33 |
| Allen | United States | 2 | 313:59 |
| Bluford | United States | 2 | 313:53 |
| Thornton, W. | United States | 2 | 313:18 |
| Musgrave | United States | 2 | 311:10 |
| Nelson, G. | United States | 2 | 310:44 |
| Evans | United States | 1 | 301:52 |
| Schmitt | United States | 1 | 301:52 |
| Titov, V.* | U.S.S.R | 2 | [3] 298:00 |
| Schirra | United States | 3 | 295:13 |
| Irwin | United States | 1 | 295:12 |
| Worden | United States | 1 | 295:12 |
| Overmyer | United States | 2 | 290:23 |
| Aldrin | United States | 2 | 289:54 |
| Stewart | United States | 2 | 289:01 |
| Hawley | United States | 2 | 288:01 |
| Aksenov | U.S.S.R | 2 | 284:15 |
| Malyshev | U.S.S.R | 2 | 284:02 |
| Volk | U.S.S.R | 1 | 283:14 |
| Collins | United States | 2 | 266:06 |
| Duke | United States | 1 | 265:51 |
| Filipchenko | U.S.S.R | 2 | 261:05 |
| Eisele | United States | 1 | 260:09 |
| Cunningham | United States | 1 | 260:09 |
| Manarov* | U.S.S.R | 1 | [3] 249:42 |
| Lichtenberg | United States | 1 | 247:47 |
| Merbold | United States/ESA | 1 | 247:47 |
| Parker | United States | 1 | 247:47 |
| Buchli | United States | 2 | 242:17 |
| Schweickart | United States | 1 | 241:01 |
| Serebrov | U.S.S.R | 2 | 238:10 |
| Shatalov | U.S.S.R | 3 | 237:59 |
| Rukavishnikov | U.S.S.R | 3 | 237:11 |
| Cooper | United States | 2 | 225:15 |
| Engle | United States | 2 | 224:31 |
| Slayton | United States | 1 | 217:28 |
| Shepard, A. | United States | 2 | 216:17 |
| Mitchell | United States | 1 | 216:02 |
| Roosa | United States | 1 | 216:02 |
| Yeliseyev | U.S.S.R | 3 | 214:25 |
| Armstrong | United States | 2 | 206:00 |
| Truly | United States | 2 | 199:22 |
| Leestma | United States | 1 | 197:24 |
| McBride | United States | 1 | 197:24 |
| Garneau | United States/Canada | 1 | 197:24 |
| Scully-Power | United States | 1 | 197:24 |
| Sullivan | United States | 1 | 197:24 |
| Fisher, A. | United States | 1 | 191:45 |
| Walker, D. | United States | 1 | 191:45 |
| McCandless | United States | 1 | 191:16 |
| McNair | United States | 1 | 191:16 |
| Viktorenko | U.S.S.R | 1 | 191:05 |
| Faris | U.S.S.R./Syria | 1 | 191:05 |
| Acton | United States | 1 | 190:46 |
| Bartoe | United States | 1 | 190:46 |
| England | United States | 1 | 190:46 |
| Henize | United States | 1 | 190:46 |
| Bridges | United States | 1 | 190:46 |

## TABLE 19.—COMPARATIVE DATA ON ASTRONAUT AND COSMONAUT CUMULATIVE TIME IN SPACE—Continued

| Name | Country | Number of flights | Cumulative time (hrs:min) |
|---|---|---|---|
| Remek | U.S.S.R./Czechoslovakia | 1 | 190:17 |
| Hermaszewski | U.S.S.R./Poland | 1 | 190:04 |
| Levchenko | U.S.S.R | 1 | 189:58 |
| Chretien | U.S.S.R./France | 1 | 189:51 |
| Sharma | U.S.S.R./India | 1 | 189:41 |
| Jähn | U.S.S.R./GDR | 1 | 188:49 |
| Farkas | U.S.S.R./Hungary | 1 | 188:46 |
| Tamayo Mendez | U.S.S.R./Cuba | 1 | 188:43 |
| Pham Tuan | U.S.S.R./Vietnam | 1 | 188:42 |
| Prunariu | U.S.S.R./Romania | 1 | 188:41 |
| Gurragcha | U.S.S.R./Mongolia | 1 | 186:43 |
| Covey | United States | 1 | 170:18 |
| Lounge | United States | 1 | 170:18 |
| Fisher, W. | United States | 1 | 170:18 |
| Al-Saud | United States/Saudi Arabia | 1 | 169:39 |
| Baudry | United States/France | 1 | 169:39 |
| Creighton | United States | 1 | 169:39 |
| Lucid | United States | 1 | 169:39 |
| Ockels | United States/ESA | 1 | 168:44 |
| Furrer | United States/FRG | 1 | 168:44 |
| Messerschmid | United States/FRG | 1 | 168:44 |
| Dunbar | United States | 1 | 168:44 |
| Leonov | U.S.S.R | 2 | 168:33 |
| Gregory | United States | 1 | 168:09 |
| Lind | United States | 1 | 168:09 |
| Vandenberg | United States | 1 | 168:09 |
| Wang | United States | 1 | 168:09 |
| Griggs | United States | 1 | 167:55 |
| Hoffman | United States | 1 | 167:55 |
| Seddon | United States | 1 | 167:55 |
| Williams, D. | United States | 1 | 167:55 |
| Garn | United States | 1 | 167:55 |
| Hart | United States | 1 | 167:40 |
| Scobee | United States | 1 | 167:40 |
| O'Connor | United States | 1 | 165:04 |
| Spring | United States | 1 | 165:04 |
| Cleave | United States | 1 | 165:04 |
| Ross | United States | 1 | 165:04 |
| Neri | United States/Mexico | 1 | 165:04 |
| Anders | United States | 1 | 147:01 |
| Coats | United States | 1 | 144:57 |
| Mullane | United States | 1 | 144:57 |
| Resnik | United States | 1 | 144:57 |
| Nelson, B. | United States | 1 | 143:04 |
| Cenker | United States | 1 | 143:04 |
| Chang-Diaz | United States | 1 | 143:04 |
| Bolden | United States | 1 | 143:04 |
| Haise | United States | 1 | 142:55 |
| Swigert | United States | 1 | 142:55 |
| Lenoir | United States | 1 | 122:14 |
| Peterson | United States | 1 | 120:24 |
| Shonin | U.S.S.R | 1 | 118:42 |
| White | United States | 1 | 97:56 |
| Grabe | United States | 1 | 97:45 |
| Hilmers | United States | 1 | 97:45 |
| Pailes | United States | 1 | 97:45 |
| Beregovoy | U.S.S.R | 1 | 94:51 |
| Shriver | United States | 1 | 73:33 |
| Onizuka | United States | 1 | 73:33 |
| Payton | United States | 1 | 73:33 |

## TABLE 19.—COMPARATIVE DATA ON ASTRONAUT AND COSMONAUT CUMULATIVE TIME IN SPACE—Continued

| Name | Country | Number of flights | Cumulative time (hrs:min) |
|---|---|---|---|
| Tereshkova | U.S.S.R | 1 | 70:50 |
| Komarov | U.S.S.R | 2 | 50:54 |
| Demin | U.S.S.R | 1 | 48:12 |
| Sarafanov | U.S.S.R | 1 | 48:12 |
| Rozhdestvenskiy | U.S.S.R | 1 | 48:06 |
| Zudov | U.S.S.R | 1 | 48:06 |
| Khrunov | U.S.S.R | 1 | 47:49 |
| Lazarev | U.S.S.R | 2 | 47:36 |
| Ivanov | U.S.S.R./Bulgaria | 1 | 47:01 |
| Bel'yayev | U.S.S.R | 1 | 26:02 |
| Titov, G. | U.S.S.R | 1 | 25:18 |
| Yegorov | U.S.S.R | 1 | 24:17 |
| Feoktistov | U.S.S.R | 1 | 24:17 |
| Grissom | United States | 2 | 5:09 |
| Carpenter | United States | 1 | 4:56 |
| Glenn | United States | 1 | 4:55 |
| Gagarin | U.S.S.R | 1 | 1:48 |

[1] 431 days.
[2] 84 days.
[3] For V. Titov and Manarov, cumulative time includes Soyuz TM-4 mission through December 31, 1987. Mission still in progress at this writing.

| | |
|---|---|
| United States | 120 |
| United States/foreign | 8 |
| Subtotal | 128 |
| U.S.S.R | 64 |
| U.S.S.R./foreign | 12 |
| Subtotal | 76 |
| Total | 204 |

## TABLE 20.—COSMONAUT CUMULATIVE SPACE AND EVA TIMES

| Cosmonaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) |
|---|---|---|---|
| Aksenov | Soyuz 22 | 284:15 | |
| | Soyuz T-2 | | |
| Aleksandrov | Soyuz T-9 | 7,433:03 | 5:45 |
| | Soyuz TM-3 | | |
| Artyukhin | Soyuz 14 | 377:30 | |
| Atkov | Soyuz T-10 | 5,686:50 | |
| Bel'yayev | Voskhod 2 | 26:02 | |
| Beregovoy | Soyuz 3 | 94:51 | |
| Berezovoy | Soyuz T-5/T-7 | 5,073:05 | 2:33 |
| Bykovskiy | Vostok 5 | 497:49 | |
| | Soyuz 22 | | |
| | Soyuz 31/29 | | |
| Chretien (France) | Soyuz T-6 | 189:51 | |
| Demin | Soyuz 15 | 48:12 | |
| Dobrovolskiy | Soyuz 11 | 570:22 | |
| Dzhanibekov | Soyuz 27 | 3,495:59 | 8:35 |
| | Soyuz 39 | | |
| | Soyuz T-6 | | |
| | Soyuz T-12 | | |
| | Soyuz T-13 | | |
| Faris (Syria) | Soyuz TM-3/TM-2 | 191:05 | |
| Farkas (Hungary) | Soyuz 36/35 | 188:46 | |
| Feoktistov | Voskhod 1 | 24:17 | |

TABLE 20.—COSMONAUT CUMULATIVE SPACE AND EVA TIMES—Continued

| Cosmonaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) |
|---|---|---|---|
| Filipchenko | Soyuz 7 | 261:05 | ........ |
| | Soyuz 16 | | |
| Gagarin | Vostok 1 | 1:48 | ........ |
| Glazkov | Soyuz 24 | 425:23 | ........ |
| Gorbatko | Soyuz 7 | 732:46 | ........ |
| | Soyuz 24 | | |
| | Soyuz 37/36 | | |
| Grechko | Soyuz 17 | 3,236:33 | 1:28 |
| | Soyuz 26 | | |
| | Soyuz T-14 | | |
| Gubarev | Soyuz 17 | 899:37 | ........ |
| | Soyuz 26 | | |
| Gurragcha (Mongolia) | Soyuz 39 | 186:43 | ........ |
| Hermaszewski (Poland) | Soyuz 30 | 190:04 | ........ |
| Ivanchenkov | Soyuz 29/31 | 3,540:39 | 2:05 |
| | Soyuz T-6 | | |
| Ivanov (Bulgaria) | Soyuz 33 | 47:01 | ........ |
| Jähn (E. Germany) | Soyuz 31/29 | 188:49 | ........ |
| Khrunov | Soyuz 4/5 | 47:49 | 1:00 |
| Kizim | Soyuz T-3 | 8,993:59 | 31:40 |
| | Soyuz T-10 | | |
| | Soyuz T-15 | | |
| Klimuk | Soyuz 13 | 1,890:19 | ........ |
| | Soyuz 18 | | |
| | Soyuz 30 | | |
| Komarov | Voskhod 1 | 50:54 | ........ |
| | Soyuz 1 | | |
| Kovalenok | Soyuz 25 | 5,194:12 | 2:05 |
| | Soyuz 29/31 | | |
| | Soyuz T-4 | | |
| Kubasov | Soyuz 6 | 449:59 | ........ |
| | Soyuz 19 | | |
| | Soyuz 36/35 | | |
| Laveikin | Soyuz TM-2/TM-3 | 4,179:26 | 8:48 |
| Lazarev | Soyuz 12 | 47:36 | ........ |
| | Soyuz 18A | | |
| Lebedev | Soyuz 13 | 5,262:00 | 2:33 |
| | Soyuz T-5/T-7 | | |
| Leonov | Voskhod 2 | 168:33 | 0:24 |
| | Soyuz 19 | | |
| Levchenko | Soyuz TM-4/TM-3 | 189:58 | ........ |
| Lyakhov | Soyuz 32/34 | 7,786:22 | 7:08 |
| | Soyuz T-9 | | |
| Makarov | Soyuz 12 | 497:43 | ........ |
| | Soyuz 18A | | |
| | Soyuz 27 | | |
| | Soyuz T-3 | | |
| Malyshev | Soyuz T-2 | 284:02 | ........ |
| | Soyuz T-11 | | |
| Manarov [1] | Soyuz TM-4 [1] | [1]249:42 | (1) |
| Nikolayev | Vostok 3 | 519:24 | ........ |
| | Soyuz 9 | | |
| Patsayev | Soyuz 11 | 570:22 | ........ |
| Pham Tuan (Vietnam) | Soyuz 37/36 | 188:42 | ........ |
| Popov | Soyuz 35/37 | 4,814:45 | ........ |
| | Soyuz 40 | | |
| | Soyuz T-7/T-5 | | |
| Popovich | Vostok 4 | 448:29 | ........ |
| | Soyuz 14 | | |
| Prunariu (Romania) | Soyuz 40 | 188:41 | ........ |
| Remek (Czech.) | Soyuz 28 | 190:17 | ........ |

## TABLE 20.—COSMONAUT CUMULATIVE SPACE AND EVA TIMES—Continued

| Cosmonaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) |
|---|---|---|---|
| Romanenko | Soyuz 26 | 10,338:21 | 8:48 |
| | Soyuz 38 | | |
| | Soyuz TM-2/TM-3 | | |
| Rozhdestvenskiy | Soyuz 23 | 48:06 | |
| Rukavishnikov | Soyuz 10 | 237:11 | |
| | Soyuz 16 | | |
| | Soyuz 33 | | |
| Ryumin | Soyuz 25 | 8,685:34 | 1:23 |
| | Soyuz 32/34 | | |
| | Soyuz 35/37 | | |
| Sarafanov | Soyuz 15 | 48:12 | |
| Savinykh | Soyuz T-4 | 5,830:29 | 5:00 |
| | Soyuz T-13 | | |
| Savitskaya | Soyuz T-7/T-5 | 473:06 | 3:35 |
| | Soyuz T-12 | | |
| Serebrov | Soyuz T-7/T-5 | 238:10 | |
| | Soyuz T-8 | | |
| Sevest'yanov | Soyuz 9 | 1,936:19 | |
| | Soyuz 18 | | |
| Sharma | Soyuz T-11 | 189:41 | |
| Shatalov | Soyuz 4 | 237:59 | |
| | Soyuz 8 | | |
| | Soyuz 10 | | |
| Shonin | Soyuz 6 | 118:42 | |
| Solovyev | Soyuz T-10 | 8,686:51 | 31:40 |
| | Soyuz T-15 | | |
| Strekalov | Soyuz T-3 | 545:07 | |
| | Soyuz T-8 | | |
| | Soyuz T-11 | | |
| | (Soyuz T-10A)[2] | | |
| Tamayo Mendez (Cuba) | Soyuz 38 | 188:43 | |
| Tereshkova | Vostok 6 | 70:50 | |
| Titov, G. | Vostok 2 | 25:18 | |
| Titov, V.[1] | Soyuz T-8 | [1]298:00 | ([1]) |
| | (Soyuz T-10A)[2] | | |
| | Soyuz TM-4[2] | | |
| Vasyutin | Soyuz T-14 | 1,557:52 | |
| Viktorenko | Soyuz TM-3/TM-2 | 191:05 | |
| Volk | Soyuz T-12 | 283:14 | |
| Volkov, A. | Soyuz T-14 | 1,557:52 | |
| Volkov, V. | Soyuz 7 | 689:03 | |
| | Soyuz 11 | | |
| Volynov | Soyuz 5 | 1,255:20 | |
| | Soyuz 21 | | |
| Yegorov Voskhod 1 | 24:17 | | |
| Yeliseyev | Soyuz 4/5 | 214:25 | 1:00 |
| | Soyuz 8 | | |
| | Soyuz 10 | | |
| Zholobov | Soyuz 21 | 1,182:24 | |
| Zudov | Soyuz 23 | 48:06 | |

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Includes all persons launched by the Soviet Union; individuals from countries other than the Soviet Union are so noted.

EVA duration has never been officially announced by the Soviets for Voskhod 2 (Leonov) or Soyuz 4 and 5 (Khrunov and Yeliseyev). The data here are roughly equivalent to "hatch opening and hatch closing" times used in the U.S. Gemini program, as near as can be determined. Other estimates exist.

[1] V. Titov and Manarov were in orbit when this table was prepared. Time accumulated through December 31, 1987 is included.

[2] Soyuz T-10A (V. Titov and Strekalov) was an attempted launch on Sept. 26, 1983 that was aborted on the pad when a fire erupted in the launch vehicle. The cosmonauts were propelled away from the launch pad by an emergency escape system and were not injured. It is not counted in the total number of flights for these men or total Soviet spaceflights, but is listed for completeness.

## TABLE 21.—ASTRONAUT CUMULATIVE TIME IN SPACE AND EVA TIMES

| Astronaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) | | |
|---|---|---|---|---|---|
| | | | Space | Lunar | Total |
| Acton | STS 51-F | 190:46 | | | |
| Aldrin | Gemini 12 | 289:54 | 5:30 | 2:48 | 8:18 |
| | Apollo 11 | | | | |
| Allen | STS–5 | 313:59 | 10:43 | | 10:43 |
| STS 51-A | | | | | |
| Al-Saud (S.Arab.) | STS 51-G | 169:39 | | | |
| Anders | Apollo 8 | 147:01 | | | |
| Armstrong | Gemini 8 | 206:00 | | 2:48 | 2:48 |
| | Apollo 11 | | | | |
| Bean | Apollo 11 | 1,671:45 | 2:41 | 7:46 | 10:27 |
| | Skylab 3 | | | | |
| Bluford | STS–8 | 313:53 | | | |
| | STS 61-A | | | | |
| Bobko | STS–6 | 386:04 | | | |
| | STS 51-D | | | | |
| | STS 51-J | | | | |
| Bolden | STS 61-C | 143:04 | | | |
| Borman | Gemini 7 | 477:36 | | | |
| | Apollo 8 | | | | |
| Brand | ASTP | 530:58 | | | |
| | STS–5 | | | | |
| | STS 41-B | | | | |
| Brandenstein | STS–8 | 314:48 | | | |
| | STS 51-G | | | | |
| Bridges | STS 51-F | 190:46 | | | |
| Buchli | STS 51-C | 242:17 | | | |
| | STS 61-A | | | | |
| Carpenter | MA–7 | 4:56 | | | |
| Carr | Skylab 4 | 2017:16 | 15:51 | | 15:51 |
| Cenker | STS 61-C | 143:04 | | | |
| Cernan | Gemini 9 | 566:16 | 2:07 | 22:04 | 24:11 |
| | Apollo 10 | | | | |
| | Apollo 17 | | | | |
| Chang-Diaz | STS 61-C | 143:04 | | | |
| Cleave | STS 61-B | 165:04 | | | |
| Coats | STS 41-D | 144:57 | | | |
| Collins | Gemini 10 | 266:06 | 1:27 | | 1:27 |
| | Apollo 11 | | | | |
| Conrad | Gemini 5 | 1,179:38 | 4:59 | 7:46 | 12:45 |
| | Gemini 11 | | | | |
| | Apollo 12 | | | | |
| | Skylab 2 | | | | |
| Cooper | MA–9 | 225:15 | | | |
| | Gemini 9 | | | | |
| Covey | STS 51-I | 170:18 | | | |
| Creighton | STS 51-G | 169:39 | | | |
| Crippen | STS–1 | 565:49 | | | |
| | STS–7 | | | | |
| | STS 41-C | | | | |
| | STS 41-G | | | | |
| Cunningham | Apollo 7 | 260:09 | | | |
| Duke | Apollo 16 | 265:51 | 1:24 | 20:14 | 21:38 |
| Dunbar | STS 61-A | 168:44 | | | |
| Eisele | Apollo 7 | 260:09 | | | |
| England | STS 51-F | 190:46 | | | |
| Engle | STS–2 | 224:31 | | | |
| | STS 51-I | | | | |
| Evans | Apollo 17 | 301:52 | 1:06 | | 1:06 |
| Fabian | STS–7 | 316:03 | | | |
| | STS 51-G | | | | |
| Fisher, A. | STS 51-A | 191:45 | | | |

## TABLE 21.—ASTRONAUT CUMULATIVE TIME IN SPACE AND EVA TIMES—Continued

| Astronaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) | | |
|---|---|---|---|---|---|
| | | | Space | Lunar | Total |
| Fisher, W. | STS 51-I | 170:18 | 11:38 | | 11:38 |
| Fullerton | STS–3<br>STS 51-F | 382:51 | | | |
| Furrer (FRG) | STS 61-A | 168:44 | | | |
| Gardner, D. | STS–8<br>STS 51-A | 336:54 | 10:43 | | 10:43 |
| Garn | STS 51-D | 167:55 | | | |
| Garneau (Canada) | STS 41-G | 197:24 | | | |
| Garriott | Skylab 3<br>STS–9 | 1,674:56 | 13:42 | | 13:42 |
| Gibson, E. | Skylab 4 | 2,017:16 | 15:22 | | 15:22 |
| Gibson, R. | STS 41-B<br>STS 61-C | 334:20 | | | |
| Glenn | MA–6 | 4:55 | | | |
| Gordon | Gemini 11<br>Apollo 12 | 315:53 | 2:41 | | 2:41 |
| Grabe | STS 51-J | 97:45 | | | |
| Gregory | STS 51-B | 168:09 | | | |
| Griggs | STS 51-D | 167:55 | 3:00 | | 3:00 |
| Grissom | MR–4<br>Gemini 3<br>(Apollo 204)[1] | 5:09 | | | |
| Haise | Apollo 13 | 142:55 | | | |
| Hart | STS 41-C | 167:40 | | | |
| Hartsfield | STS–4<br>STS 41-D<br>STS 61-A | 482:51 | | | |
| Hauck | STS 7<br>STS 51-A | 337:09 | | | |
| Hawley | STS 41-D<br>STS 61-C | 288:01 | | | |
| Henize | STS 51-F | 190:46 | | | |
| Hilmers | STS 51-J | 97:45 | | | |
| Hoffman | STS 51-D | 167:55 | 3:00 | | 3:00 |
| Irwin | Apollo 15 | 295:12 | :38 | 18:35 | 19:13 |
| Kerwin | Skylab 2 | 672:50 | 3:23 | | 3:23 |
| Leestma | STS 41-B | 197:24 | 3:30 | | 3:30 |
| Lenoir | STS–5 | 122:14 | | | |
| Lichtenberg | STS–9 | 247:47 | | | |
| Lind | STS 51-B | 168:09 | | | |
| Lounge | STS 51-I | 170:18 | | | |
| Lousma | Skylab 3<br>STS–3 | 1,619:14 | 11:01 | | 11:01 |
| Lovell | Gemini 7<br>Gemini 12<br>Apollo 8<br>Apollo 13 | 715:06 | | | |
| Lucid | STS 51-G | 169:39 | | | |
| Mattingly | Apollo 16<br>STS–4<br>STS 51-C | 508:34 | 1:24 | | 1:24 |
| McBride | STS 41-G | 197:24 | | | |
| McCandless | STS 41-B | 191:16 | | | |
| McDivitt | Gemini 4<br>Apollo 9 | 338:57 | | | |
| McNair | STS 41-B<br>(STS 51-L)[1] | 191:16 | 11:30 | | 11:30 |
| Merbold (ESA) | STS–9 | 247:47 | | | |
| Messerschmid (FRG) | STS 61-A | 168:44 | | | |
| Mitchell | Apollo 14 | 216:02 | | 9:23 | 9:23 |
| Mullane | STS 41-D | 144:57 | | | |

## TABLE 21.—ASTRONAUT CUMULATIVE TIME IN SPACE AND EVA TIMES—Continued

| Astronaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) | | |
|---|---|---|---|---|---|
| | | | Space | Lunar | Total |
| Musgrave | STS–6 | 311:10 | 3:52 | | 3:52 |
| | STS 51-F | | | | |
| Nagel | STS 51-G | 338:23 | | | |
| | STS 61-A | | | | |
| Nelson, B. | STS 61-C | 143:04 | | | |
| Nelson, G. | STS 41-C | 310:44 | 10:30 | | 10:30 |
| | STS 61-C | | | | |
| Neri (Mexico) | STS 61-B | 165:04 | | | |
| Ockels (ESA) | STS 61-A | 168:44 | | | |
| O'Connor | STS 61-B | 165:04 | | | |
| Onizuka | STS 51-C | 73:33 | | | |
| | (STS 51-L)[1] | | | | |
| Overmyer | STS–5 | 290:23 | | | |
| | STS 51-B | | | | |
| Pailes | STS 51-J | 97:45 | | | |
| Parker | STS–9 | 247:47 | | | |
| Payton | STS 51-C | 73:33 | | | |
| Peterson | STS–6 | 120:24 | 3:52 | | 3:52 |
| Pogue | Skylab 4 | 2,017:16 | 13:37 | | 13:37 |
| Resnik | STS 41-D | 144:57 | | | |
| | (STS 51-L)[1] | | | | |
| Ride | STS–7 | 343:48 | | | |
| | STS 41-G | | | | |
| Roosa | Apollo 14 | 216:02 | | | |
| Ross | STS 61-B | 165:04 | 12:12 | | 12:12 |
| Schirra | MA–8 | 295:13 | | | |
| | Gemini 6 | | | | |
| | Apollo 7 | | | | |
| Schmitt | Apollo 17 | 301:52 | 1:06 | 22:04 | 23:10 |
| Schweickart | Apollo 9 | 241:01 | 1:07 | | 1:07 |
| Scobee | STS 41-C | 167:40 | | | |
| | (STS 51-L)[1] | | | | |
| Scott | Gemini 8 | 546:54 | 1:01 | 10:08 | 20:09 |
| | Apollo 9 | | | | |
| | Apollo 15 | | | | |
| Scully-Power | STS 41-G | 197:24 | | | |
| Seddon | STS 51-D | 167:55 | | | |
| Shaw | STS–9 | 412:51 | | | |
| | STS 61-B | | | | |
| Shepard, A. | MR–3 | 216:17 | | 9:23 | 9:23 |
| | Apollo 14 | | | | |
| Shriver | STS 51-C | 73:33 | | | |
| Slayton | ASTP | 217:28 | | | |
| Spring | STS 61-B | 165:04 | 12:12 | | 12:12 |
| Stafford | Gemini 6 | 507:43 | | | |
| | Gemini 9 | | | | |
| | Apollo 10 | | | | |
| | ASTP | | | | |
| Stewart | STS 41-B | 289:01 | 11:30 | | 11:30 |
| | STS 51-J | | | | |
| Sullivan | STS 41-G | 197:24 | 3:30 | | 3:30 |
| Swigert | Apollo 13 | 142:55 | | | |
| Thagard | STS–7 | 314:33 | | | |
| | STS 51-B | | | | |
| Thornton, W. | STS–8 | 313:18 | | | |
| | STS 51-B | | | | |
| Truly | STS–2 | 199:22 | | | |
| | STS–8 | | | | |
| Vandenberg | STS 51-B | 168:09 | | | |
| van Hoften | STS 41-C | 337:58 | 22:08 | | 22:08 |
| | STS 51-I | | | | |

## TABLE 21.—ASTRONAUT CUMULATIVE TIME IN SPACE AND EVA TIMES—Continued

| Astronaut | Flights | Total time in space (hrs:min) | EVA (hrs:min) | | |
|---|---|---|---|---|---|
| | | | Space | Lunar | Total |
| Walker, C. | STS 41-D | 477:56 | | | |
| | STS 51-D | | | | |
| | STS 61-B | | | | |
| Walker, D. | STS 51-A | 191:45 | | | |
| Wang | STS 51-B | 168:09 | | | |
| Weitz | Skylab 2 | 793:14 | 2:11 | | 2:11 |
| | STS–6 | | | | |
| White | Gemini 4 | 97:56 | 0:36 | | 0:36 |
| | (Apollo 204) [1] | | | | |
| Williams, D. | STS 41-D | 167:55 | | | |
| Worden | Apollo 15 | 295:12 | 0:38 | | 0:38 |
| Young | Gemini 3 | 835:42 | | 20:14 | 20:14 |
| | Gemini 10 | | | | |
| | Apollo 10 | | | | |
| | Apollo 16 | | | | |
| | STS–1 | | | | |
| | STS–9 | | | | |

Includes all persons launched by the United States; individuals from other countries are so noted.

MA=Mercury Atlas; MR=Mercury Redstone; ASTP=Apollo Soyuz Test Project; STS=Space Transportation System (the space shuttle). ESA=European Space Agency; FRG=Federal Republic of Germany.

[1] Apollo 204 was not a spaceflight, but three astronauts were killed in the Apollo 204 capsule during pre-launch tests on January 27, 1967. STS 51-L was the fatal flight of the space shuttle Challenger that killed 7 astronauts on January 28, 1986. Although neither is counted in the total number of U.S. spaceflights nor the total number of flights made by the astronauts involved, they are included here for completeness if the astronaut had made other flights. In addition to Gus Grissom and Ed White, Roger Chaffee was killed in the Apollo 204 fire. In addition to Dick Scobee, Judy Resnik, Ron McNair and Ellison Onizuka, three others died in the Challenger tragedy: Mike Smith, a NASA astronaut; Gregory Jarvis, a payload specialist from Hughes Aircraft; and Christa McAuliffe, "teacher-in-space."

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| 1961: | | | | | | |
| April 12 | Vostok 1 | Gagarin | 4,725 | 1:48 | Same | 1:48 |
| May 5 | MR–3 | Shepard | 1,290 | :15 | Same | :15 |
| July 21 | MR–4 | Grissom | 1,286 | :16 | Same | :31 |
| August 6 | Vostok 2 | G. Titov | 4,731 | 25:18 | Same | 27:06 |
| 1962: | | | | | | |
| February 20 | MA–6 | Glenn | 1,355 | 4:55 | Same | 5:26 |
| May 24 | MA–7 | Carpenter | 1,349 | 4:56 | Same | 10:22 |
| August 11 | Vostok 3 | Nikolayev | 4,722 | 94:22 | Same | 121:28 |
| August 12 | Vostok 4 | Popovich | 4,728 | 70:57 | Same | 192:25 |
| October 3 | MA–8 | Schirra | 1,373 | 9:13 | Same | 19:35 |
| 1963: | | | | | | |
| May 15 | MA–9 | Cooper | 1,376 | 34:20 | Same | 53:55 |
| June 14 | Vostok 5 | Bykovskiy | 4,720 | 119:06 | Same | 311:31 |
| June 16 | Vostok 6 | Tereshkova | 4,713 | 70:50 | Same | 382:21 |
| 1964: | | | | | | |
| October 12 | Voskhod 1 | Komarov | 5,320 | 24:17 | Same | 455:12 |
| | | Yegorov | | | | |
| | | Feoktistov | | | | |
| 1965: | | | | | | |
| March 18 | Voskhod 2 | Belyayev | 5,682 | 26:02 | Same | 507:16 |
| | | Leonov | | | | |
| March 23 | Gemini 3 | Grissom (2) | 3,225 | 4:53 | Same | 63:41 |
| | | Young | | | | |
| June 3 | Gemini 4 | McDivitt | 3,574 | 97:56 | Same | 259:33 |
| | | White | | | | |
| August 21 | Gemini 5 | Cooper (2) | 3,605 | 190:55 | Same | 641:23 |
| | | Conrad | | | | |

### TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| December 4 | Gemini 6 | Borman | 3,663 | 330:55 | Same | 1,302:33 |
| | | Lovell | | | | |
| December 15 | Gemini 7 | Schirra (2) | 3,546 | 25:51 | Same | 1,354:15 |
| | | Stafford | | | | |
| 1966: | | | | | | |
| March 16 | Gemini 8 | Armstrong | 3,788 | 10:41 | Same | 1,375:37 |
| | | Scott | | | | |
| June 3 | Gemini 9 | Stafford (2) | 3,750 | 72:21 | Same | 1,520:19 |
| | | Cernan | | | | |
| July 18 | Gemini 10 | Young (2) | 3,741 | 70:47 | Same | 1,661:53 |
| | | Collins | | | | |
| September 12 | Gemini 11 | Conrad (2) | 3,860 | 71:17 | Same | 1,804:27 |
| | | Gordon | | | | |
| November 11 | Gemini 12 | Lovell (2) | 3,763 | 94:35 | Same | 1,993:37 |
| | | Aldrin | | | | |
| 1967: | | | | | | |
| January 27 | AS–204 | Grissom (3) [1] | 20,412 | (1) | (1) | (1) |
| | | White (2) [1] | | | | |
| | | Chaffee [1] | | | | |
| | | White (2) [1] | | (1) | (1) | (1) |
| | | Chaffee [1] | | (1) | (1) | (1) |
| April 23 | Soyuz 1 | Komarov (2) | 6,450 | 26:48 | Same | 534:04 |
| 1968: | | | | | | |
| October 11 | Apollo 7 | Schirra (3) | 2,0569 | 260:09 | Same | 2,774:04 |
| | | Eisele | | | | |
| | | Cunningham | | | | |
| October 26 | Soyuz 3 | Beregovoy | 6,575 | 94.51 | Same | 628:55 |
| December 21 | Apollo 8 | Borman (2) | 43,663 | 147:01 | Same | 3,215:07 |
| | | Lovell (3) | | | | |
| | | Anders | | | | |
| 1969: | | | | | | |
| January 14 | Soyuz 4 [2] | Shatalov | 6,625 | 71:21 | Same | 795:54 |
| | | (Yeliseyev) | | | | |
| | | (Khrunov) | | | | |
| January 15 | Soyuz 5 [2] | Volynov | 6,585 | 72:54 | Same | 868:48 |
| | | Yeliseyev | | | | |
| | | Khrunov | | | 47:49 | |
| March 3 | Apollo 9 | McDivitt (2) | 4,3185 | 241:01 | Same | 3,938:10 |
| | | Scott (2) | | | | |
| | | Schweickart | | | | |
| May 18 | Apollo 10 | Stafford (3) | 48,638 | 192:03 | Same | 4,514:19 |
| | | Young (3) | | | | |
| | | Cernan (2) | | | | |
| July 16 | Apollo 11 | Armstrong (2) | 49,698 | 195:19 | Same | 5,100:16 |
| | | Collins (2) | | | | |
| | | Aldrin (2) | | | | |
| October 11 | Soyuz 6 | Shonin | 6,577 | 118:43 | Same | 1,106:14 |
| | | Kubasov | | | | |
| October 12 | Soyuz 7 | Filipchenko | 6,570 | 118:40 | Same | 1,462:14 |
| | | Gorbatko | | | | |
| | | V. Volkov | | | | |
| October 13 | Soyuz 8 | Shatalov (2) | 6,646 | 118:51 | Same | 1,699:56 |
| | | Yeliseyev (2) | | | | |
| November 14 | Apollo 12 | Conrad (3) | 49,804 | 244:36 | Same | 5,834:04 |
| | | Gordon (2) | | | | |
| | | Bean | | | | |
| 1970: | | | | | | |
| April 11 | Apollo 13 | Lovell (4) | 49,990 | 142:55 | Same | 6,262:49 |
| | | Haise | | | | |
| | | Swigert | | | | |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| June 1 | Soyuz 9 | Nikolayev (2)<br>Sevastyanov | 6,500 | 424:59 | Same | 2,549:54 |
| 1971: | | | | | | |
| January 31 | Apollo 14 | Shepard (2)<br>Roosa<br>Mitchell | 46,347 | 216:02 | Same | 6,910:55 |
| April 19 | Salyut 1 | (Occupied by Soyuz 11 crew) | 18,600 | | | |
| April 22 | Soyuz 10 | Shatalov (3)<br>Yeliseyev (3)<br>Rukavishnikov | 6,575 | 47:46 | Same | 2,693:12 |
| June 6 | Soyuz 11 | Dobrovolskiy [2]<br>V. Volkov (2) [2]<br>Patsayev [2] | 6,575 | 570:22 | Same | 4,404:18 |
| July 26 | Apollo 15 | Scott (3)<br>Irwin<br>Worden | 52,759 | 295:12 | Same | 7,796:31 |
| 1972: | | | | | | |
| April 16 | Apollo 16 | Young (4)<br>Duke | 51,571 | 265:51 | Same | 8,594:04 |
| December 7 | Apollo 17 | Cernan (3)<br>Schmitt<br>Evans | 51,808 | 301:52 | Same | 9,499:40 |
| 1973: | | | | | | |
| May 14 | Skylab 1 | (Occupied by Skylab 2, 3 and 4 crews). | 89,439 | | | |
| May 25 | Skylab 2 | Conrad (4)<br>Kerwin<br>Weitz | 30,803 | 672:50 | Same | 11,518:10 |
| July 28 | Skylab 3 | Bean (2)<br>Garriott<br>Lousma | 30,694 | 1,427:09 | Same | 15,799:37 |
| September 27 | Soyuz 12 | Lazarev<br>Makarov | 6,575 | 47:16 | Same | 4,498:50 |
| November 16 | Skylab 4 | Carr<br>Gibson<br>Pogue | 31,232 | 2,017:16 | Same | 21,851:25 |
| December 18 | Soyuz 13 | Klimuk<br>Lebedev | 6,575 | 188:56 | Same | 4,876:42 |
| 1974: | | | | | | |
| June 24 | Salyut 3 | (Occupied by Soyuz 14 crew) | 18,900 | | | |
| July 3 | Soyuz 14 | Popovich (2)<br>Artyukhin | 6,570 | 337:30 | Same | 5,631:42 |
| August 26 | Soyuz 15 | Sarafanov<br>Demin | 6,570 | 48:12 | Same | 5,728:06 |
| December 2 | Soyuz 16 | Filipchenko (2)<br>Rukavishnikov (2) | 6,570 | 142:24 | Same | 6,012:54 |
| December 26 | Salyut 4 | (Occupied by Soyuz 17, 18 crews) | 18,900 | | | |
| 1975: | | | | | | |
| January 10 | Soyuz 17 | Gubarev<br>Grechko | 6,570 | 709:20 | Same | 7,431:34 |
| April 5 | Anomaly | Lazarev (2)<br>Makarov (2) | 6,570 | :20 | Same | 7,432:14 |
| May 24 | Soyuz 18 | Klimuk (2)<br>Sevastyanov (2) | 6,570 | 1,511:20 | Same | 10,454:54 |
| July 15 | Soyuz 19 | Leonov (2)<br>Kubasov (2) | 6,800 | 142:31 | Same | 10,739:56 |
| July 15 | ASTP | Stafford (4)<br>Slayton<br>Brand | 14,743 | 217:28 | Same | 22,503:49 |
| 1976: | | | | | | |
| June 22 | Salyut 5 | (Occupied by Soyuz 21, 24 crews) | 18,900 | | | |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| July 6 | Soyuz 21 | Volynov (2)<br>Zholobov | 6,570 | 1,182:23 | Same | 13,104:42 |
| September 15 | Soyuz 22 | Bykovskiy (2)<br>Aksenov | 6,570 | 189:52 | Same | 13,484:26 |
| October 14 | Soyuz 23 | Zudov<br>Rozhdestvenskiy | 6,570 | 48:07 | Same | 13,580:40 |
| 1977: | | | | | | |
| February 7 | Soyuz 24 | Gorbatko (2)<br>Glazkov | 6,570 | 425:26 | Same | 14,431:32 |
| September 29 | Salyut 6 | (Occupied by Soyuz 26, 27, 28, 29, 30, 31 32, 35, 36, 37, 38, T2, T3, T4, 39, 40 crews). | 18,900 | | | |
| October 9 | Soyuz 25 | Kovalenok<br>Ryumin | 6,570 | 48:45 | Same | 14,592:02 |
| December 10 | Soyuz 26 | Romanenko<br>Grechko (2) | 6,570 | 898:06 | 2,314:00 | 19,157:02 |
| 1978: | | | | | | |
| January 10 | Soyuz 27 | Dzhanibekov<br>Makarov (3) | 6,570 | 1,558:53 | 142:59 | 19,443:00 |
| March 2 | Soyuz 28 | Gubarev (2)<br>Remek (Czechoslovakia) | 6,570 | 190:16 | Same | 19,832:32 |
| June 15 | Soyuz 29 | Kovalenok (2)<br>Ivanchenkov | 6,570 | 1,911:23 | 3,350:48 | 26,525:08 |
| June 27 | Soyuz 30 | Klimuk (3)<br>Hermaszewski (Poland) | 6,570 | 190:13 | Same | 26,905:14 |
| August 26 | Soyuz 31 | Bykovskiy (3)<br>Jahn (GDR) | 6,570 | 1,628:14 | 188:49 | 27,282:52 |
| 1979: | | | | | | |
| February 25 | Soyuz 32 | Lyakhov<br>Ryumin (2) (Returned unmanned) | 6,570 | 2,596:24 | 4,200:36 | 35,684:04 |
| April 10 | Soyuz 33 | Rukavishnikov (3)<br>Ivanov (Bulgaria) | 6,570 | 47:01 | Same | 35,778:06 |
| June 6 | Soyuz 34 | (Launched unmanned, returned Soyuz 32 crew). | 6,570 | 1,770:17 | | |
| 1980: | | | | | | |
| April 9 | Soyuz 35 | Popov<br>Ryumin (3) | 6,570 | 1,321:29 | 4,436:12 | 44,650:30 |
| May 26 | Soyuz 36 | Kubasov<br>Farkas (Hungary) (3) | 6,570 | 1,580:54 | 188:46 | 45,028:02 |
| June 5 | Soyuz T–2 | Malyshev<br>Aksenov (2) | 7,000 | 94:19 | Same | 45,216:40 |
| July 23 | Soyuz 37 | Gorbatko (3)<br>Pham Tuan (Viet Nam) | 6,570 | 1,911:17 | 188:42 | 45,594:04 |
| September 18 | Soyuz 38 | Romanenko (2)<br>Tamayo Mendez (Cuba) | 6,570 | 188:43 | Same | 45,971:30 |
| November 27 | Soyuz T–3 | Kizim<br>Makarov (4)<br>Strekalov | 7,000 | 307:08 | Same | 46,892:54 |
| 1981: | | | | | | |
| March 12 | Soyuz T–4 | Kovalenok<br>Savinykh (3) | 7,000 | 1,794:38 | Same | 50,482:10 |
| March 22 | Soyuz 39 | Dzhanibekov (2)<br>Gurragcha (Mongolia) | 6,570 | 188:43 | Same | 50,859:36 |
| April 12 | STS 1 | Young (5)<br>Crippen | 98,658 | 54:21 | Same | 22,612:31 |
| May 14 | Soyuz 40 | Popov (2)<br>Prunariu (Romania) | 6,570 | 188:41 | Same | 51,236:58 |
| November 12 | STS–2 | Engle<br>Truly | 103,811 | 54:13 | Same | 22,720:57 |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| 1982: | | | | | | |
| March 22 | STS–3 | Lousma (2) | 106,000 | 192:05 | Same | 23,105:07 |
| | | Fullerton | | | | |
| April 19 | Salyut 7 | (Occupied by Soyuz T–5, T–6, T–7, T–9, T–10, T–11, T–12, T–13, T–14 and T–15 crews). | 18,900 | | | |
| May 13 | Soyuz T–5 | Berezovoy | 7,000 | 2,549:06 | 5,073:05 | 61,383:08 |
| | | Lebedev (2) | | | | |
| June 24 | Soyuz T–6 | Dzhanibekov (3) | 7,000 | 189:51 | Same | 61,952:41 |
| | | Ivanchenkov (2) | | | | |
| | | Chretien (France) | | | | |
| June 27 | STS–4 | Mattingly (2) | 108,797 | 169:10 | Same | 23,443:27 |
| | | Hartsfield | | | | |
| August 19 | Soyuz T–7 | Popov (3) | 7,000 | 2,712:51 | 189:52 | 62,522:17 |
| | | Serebrov | | | | |
| | | Savitskaya | | | | |
| November 11 | STS–5 | Brand (2) | 111,201 | 122:14 | Same | 23,932:23 |
| | | Overmyer | | | | |
| | | Allen | | | | |
| | | Lenoir | | | | |
| 1983: | | | | | | |
| April 4 | STS–6 | Weitz (2) | 114,201 | 120:24 | Same | 24,413:59 |
| | | Bobko | | | | |
| | | Musgrave | | | | |
| | | Peterson | | | | |
| April 20 | Soyuz T–8 | V. Titov | 7,000 | 48:18 | Same | 62,667:11 |
| | | Strekalov (2) | | | | |
| | | Serebrov (2) | | | | |
| June 18 | STS–7 | Crippen (2) | 110,013 | 146:24 | Same | 25,145:59 |
| | | Hauck | | | | |
| | | Ride | | | | |
| | | Fabian | | | | |
| | | Thagard | | | | |
| June 27 | Soyuz T–9 | Lyakhov (2) | 7,000 | 3,585:46 | Same | 69,838:43 |
| | | Alexandrov | | | | |
| August 30 | STS–8 | Truly (2) | 104,675 | 145:09 | Same | 25,871:44 |
| | | Brandenstein | | | | |
| | | Thornton | | | | |
| | | Bluford | | | | |
| | | D. Gardner | | | | |
| Sept. 26 | Soyuz T–10 | V. Titov | (4) | (4) | (4) | (4) |
| | | Strekalov | | | | |
| November 28 | STS–9 | Young (6) | 110,031 | 247:47 | Same | 27,358:26 |
| | | Shaw | | | | |
| | | Parker | | | | |
| | | Garriott (2) | | | | |
| | | Lichtenberg | | | | |
| | | Merbold (FRG) | | | | |
| 1984: | | | | | | |
| February 3 | STS 41–B | Brand (3) | 113,508 | 191:16 | Same | 28,314:46 |
| | | R. Gibson | | | | |
| | | McCandless | | | | |
| | | McNair | | | | |
| | | Stewart | | | | |
| February 8 | Soyuz T–10 | Kizim (2) | 7,000 | 1,510:43 | 5,686:50 | 74,370:52 |
| | | Solovyev | | | | |
| | | Atkov | | | | |
| April 3 | Soyuz T–11 | Malyshev (2) | 7,000 | 4,365:48 | 189:41 | 87,468:16 |
| | | Strekalov (3) | | | | |
| | | Sharma (India) | | | | |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| April 6 | STS 41-C | Crippen (3) | 115,342 | 167:40 | Same | 29,153:06 |
| | | Scobee | | | | |
| | | Hart | | | | |
| | | van Hoften | | | | |
| | | G. Nelson | | | | |
| July 17 | Soyuz T-12 | Dzhanibekov (4) | 7,000 | 283:14 | Same | 88,317:58 |
| | | Savitskaya (2) | | | | |
| | | Volk | | | | |
| August 30 | STS 41-D | Hartsfield (2) | 119,491 | 144:57 | Same | 30,022:48 |
| | | Coats | | | | |
| | | Resnik | | | | |
| | | Hawley | | | | |
| | | Mullane | | | | |
| | | C. Walker | | | | |
| October 5 | STS 41-G | Crippen (4) | 110,119 | 197:24 | Same | 31,404:36 |
| | | McBride | | | | |
| | | Ride (2) | | | | |
| | | Sullivan | | | | |
| | | Leestma | | | | |
| | | Scully-Power | | | | |
| | | Garneau (Canada) | | | | |
| November 8 | STS 51-A | Hauck (2) | 119,421 | 191:45 | Same | 32,363:21 |
| | | D. Walker | | | | |
| | | Allen (2) | | | | |
| | | A. Fisher | | | | |
| | | D. Gardner (2) | | | | |
| 1985: | | | | | | |
| January 24 | STS 51-C | Mattingly (3) | N/A | 73:33 | Same | 32,731:06 |
| | | Shriver | | | | |
| | | Onizuka | | | | |
| | | Buchli | | | | |
| | | Payton | | | | |
| April 12 | STS 51-D | Bobko (2) | 113,802 | 167:55 | Same | 33,906:31 |
| | | Williams | | | | |
| | | Hoffman | | | | |
| | | Griggs | | | | |
| | | Seddon | | | | |
| | | C. Walker (2) | | | | |
| | | Garn | | | | |
| April 29 | STS 51-B | Overmyer (2) | 111,982 | 168:09 | Same | 35,083:34 |
| | | Gregory | | | | |
| | | Thornton (2) | | | | |
| | | Thagard (2) | | | | |
| | | Lind | | | | |
| | | van den Berg | | | | |
| | | Wang | | | | |
| June 6 | Soyuz T-13 [5] | Dzhanibekov (5) | 7,000 | 2,691:12 | 2,691:12 | 91,222:23 |
| | | Savinykh (2) | | | | |
| June 17 | STS 51-G | Brandenstein (2) | 116,310 | 169:40 | Same | 36,271:14 |
| | | Creighton | | | | |
| | | Lucid | | | | |
| | | Nagel | | | | |
| | | Fabian (2) | | | | |
| | | Bandry (France) | | | | |
| | | Sultan Salman Al-Saud (Saudi Arabia). | | | | |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| July 29 | STS 51-F | Fullerton (2) | 114,590 | 190:46 | Same | 37,606:36 |
| | | Bridges | | | | |
| | | Henize | | | | |
| | | England | | | | |
| | | Musgrave | | | | |
| | | Bartoe | | | | |
| | | Acton | | | | |
| August 27 | STS 51-I | Engle (2) | 118,981 | 170:18 | Same | 38,458:06 |
| | | Covey | | | | |
| | | Lounge | | | | |
| | | W. Fisher | | | | |
| | | van Hoften (2) | | | | |
| September 17 | Soyuz T-14[5] | Vasyutin | 7,000 | 1,557:52 | 1,557:52 | 98,373:58 |
| | | Grechko (3) | | | | |
| | | A. Volkov | | | | |
| October 3 | STS 51-J | Bobko (3) | N/A | 97:45 | Same | 38,946:51 |
| | | Grabe | | | | |
| | | Hilmers | | | | |
| | | Stewart (2) | | | | |
| | | Pailes | | | | |
| October 30 | STS 61-A | Hartsfield (3) | 110,568 | 168:44 | Same | 40,296:45 |
| | | Nagel | | | | |
| | | Buchli (2) | | | | |
| | | Bluford (2) | | | | |
| | | Dunbar | | | | |
| | | Ockels (ESA) | | | | |
| | | Furrer (FRG) | | | | |
| | | Messerschmid (FRG) | | | | |
| November 26 | STS 61-B | Shaw (2) | 118,664 | 165:05 | Same | 41,452:18 |
| | | O'Connor | | | | |
| | | Spring | | | | |
| | | Cleave | | | | |
| | | Ross | | | | |
| | | C. Walker (3) | | | | |
| | | Neri (Mexico) | | | | |
| 1986: | | | | | | |
| January 12 | STS 61-C | R. Gibson (2) | 116,120 | 143:04 | Same | 42,453:46 |
| | | Bolden | | | | |
| | | Hawley (2) | | | | |
| | | G. Nelson (2) | | | | |
| | | Chang-Diaz | | | | |
| | | Cenker | | | | |
| | | B. Nelson | | | | |
| January 28 | STS 51-L | Scobee (2) | 121,939 | (6) | (6) | (6) |
| | | Smith | | | | |
| | | Resnik (2) | | | | |
| | | Onizuka (2) | | | | |
| | | McNair | | | | |
| | | Jarvis | | | | |
| | | McAuliffe | | | | |
| February 20 | Mir | (Occupied by Soyuz T-15, TM2, TM3 and TM4 crews.). | | | | |
| March 13 | Soyuz T-15 | Kizim (3) | 7,000 | 3,000:01 | Same | 104,374:00 |
| | | Solovyev (2) | | | | |
| 1987: | | | | | | |
| February 5 | Soyuz TM-2 | Romanenko (3) | 7,070 | 4,179:26 | 7,835:38 | 116,389:04 |
| | | Laveikin | | | 4179:26 | |
| July 22 | Soyuz TM-3 | Viktorenko | 7,070 | 3,847:17 | 191:05 | 120,618:31 |
| | | A. Aleksandrov (2) | | | 3847:17 | |
| | | Faris (Syria) | | | 191:05 | |

## TABLE 22.—SUMMARY LIST OF PILOTED SPACE FLIGHTS—Continued

| Launch date | Vehicle name | Crew (Number of flights) | Weight (KGS) | Ship duration (Hr:Min) | Crew duration (Hr:Min) | National cumulative personhours |
|---|---|---|---|---|---|---|
| December 21 | Soyuz TM-4 | V. Titov (2) | 7,070 | ([7]) | ([7]) | [8] 121,307:53 |
| | | Manarov | | | ([7]) | |
| | | Levchenko | | | 189:58 | |

[1] Fatality. Not a space flight, but date of fatal fire on pad during test preliminary to later scheduled flight.

[2] Fatality.

[3] Soyuz 4 was launched carrying only Shatalov. Soyuz 5 carried Volynov, Yeliseyev and Khrunov. The latter two transferred to Soyuz 4 via a spacewalk and returned to Earth with Shatalov.

[4] Not a spaceflight. Crew jettisoned using emergency abort system after fire erupted in launch vehicle prior to launch.

[5] Soyuz T-13 and T-14 involved the first space station crew transfer. Dzhanibekov returned to Earth on his Soyuz T-13 spacecraft with Grechko who was launched in Soyuz T-14. Savinykh, who was launched on Soyus T-13, remained on the space station with Vasyutin and Volkov who were launched on Soyuz T-14.

[6] Fatality. Exploded 73 seconds after liftoff. All aboard were killed.

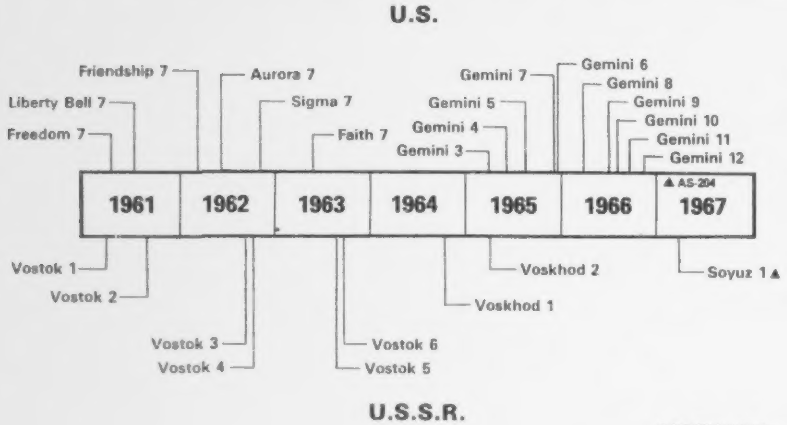
[7] In progress.

[8] Includes time accumulated by Titov and Manarov through Dec. 31, 1987.

Prepared by CRS.

Figure 4

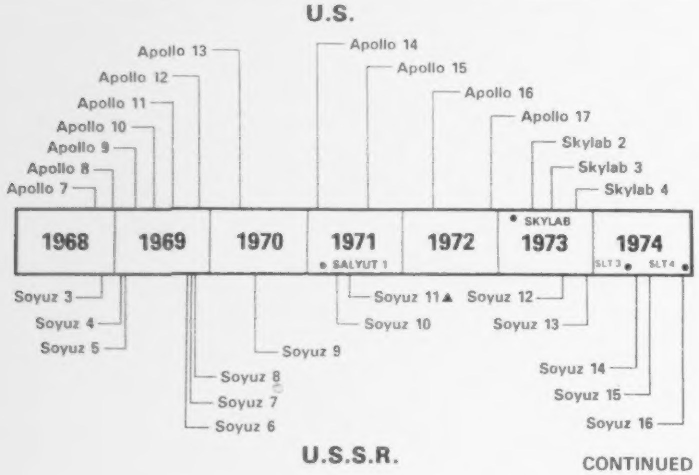
## TIME LINE OF U.S. AND U.S.S.R. PILOTED SPACE MISSIONS



CONTINUED
MSS 9-1-87

Figure 4 (cont.)

## TIME LINE OF U.S. AND U.S.S.R. PILOTED SPACE MISSIONS (continued)



CONTINUED
MSS 9-1-87

83-709 0 - 88 - 8

Figure 4 (cont.)

## TIME LINE OF U.S. AND U.S.S.R. PILOTED SPACE MISSIONS (continued)

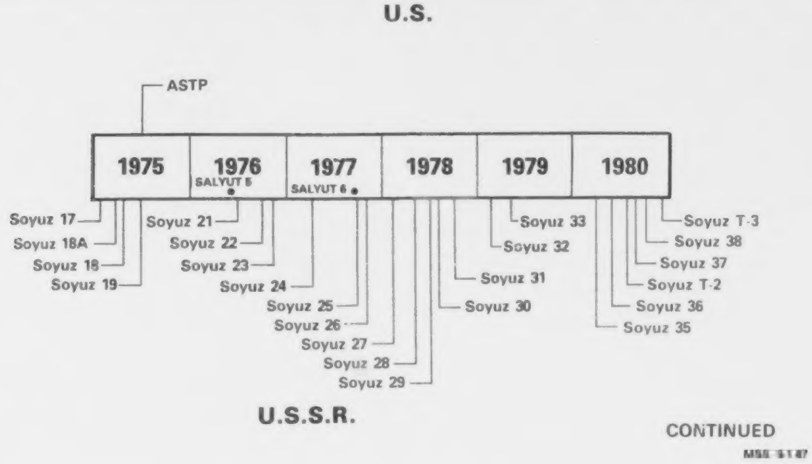
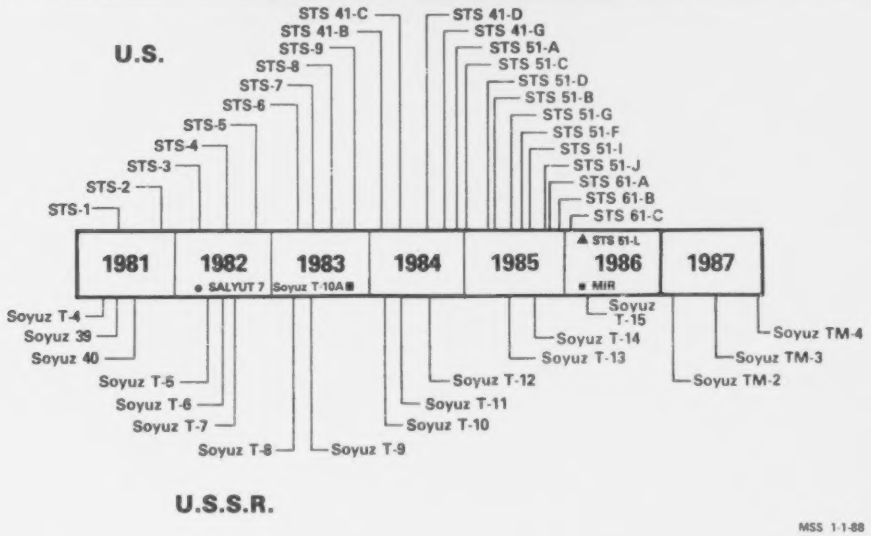


Figure 4 (cont.)

## TIME LINE OF U.S. AND U.S.S.R. PILOTED SPACE MISSIONS (continued)



# PART TWO: LAUNCH SITES, LAUNCH VEHICLES AND SUPPORT SERVICES

# CHAPTER 1—HISTORICAL SUMMARY [1]

## LAUNCH SITES

### TYURATAM (45.6°N, 63.4°E)

Then first launches of Soviet artificial Earth satellites were made from the Baikonur cosmodrome in Kazakhstan. This, the largest and most versatile of their launch sites is near the rail stop village of Tyuratam, the name commonly given to the launch site by Western analysts. Tyuratam may be considered to be analogous to Cape Canaveral and the Eastern Test Range in the United States. All launches associated with piloted spaceflight (except spaceplane tests), lunar, planetary and geosynchronous spacecraft originate from Tyuratam. The military Fractional Orbit Bombardment System (FOBS) tests in the period 1966–1971 and the antisatellite (ASAT) interceptors were launched from the F-vehicle pads at this cosmodrome.

### KAPUSTIN YAR (48.4°N, 45.8°E)

With the inauguration of the Cosmos series of satellites in 1962, a second site was used at Kapustin Yar near Volgograd. This fulfills the same function at the U.S. Wallops Island, Virginia station and the White Sands, New Mexico test area, launching small satellites and sounding rockets. The B-vehicle, no longer operational, and the C-vehicle are the only ones to have been launched from this site and annual launch totals have never exceeded the eight of 1968.

### PLESETSK (62.8°N, 40.1°E)

The third, and most widely used, launch facility is situated close to the Arctic Circle near the town of Plesetsk, which is on the railway line from Moscow to Archangelsk. Although used for some civilian communications, meteorological and international scientific launches, most satellites launched from Plesetsk have military roles and it may be considered as the Soviet equivalent of Vandenberg Air Force Base, California and the Western Test Range. Orbital inclinations attained from Plesetsk range from 62° to 83°, but satellites with retrograde orbits are launched from Tyuratam.

A summary of annual successful launch totals by site for the period 1957–1980 is given in table 23.

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[1] Previous editions of this report have been self-contained, with each new version repeating all the historical information from past editions. As the years have progressed, it has become increasingly weighty to follow this practice. Therefore, beginning with this volume, only new developments will be described in detail. Fresh information is provided whenever it amplifies or amends that presented in earlier editions. Individuals interested in reading the previous editions can access them at U.S. Government depository libraries, which include most university libraries and libraries in major cities.

TABLE 23.—RECORD OF SOVIET LAUNCHES BY SITE: 1957–1980

| | Tyuratam | Kapustin Yar | Plesetsk |
|---|---|---|---|
| Year: | | | |
| 1957 | 2 | | |
| 1958 | 1 | | |
| 1959 | 3 | | |
| 1960 | 3 | | |
| 1961 | 6 | | |
| 1962 | 13 | 7 | |
| 1963 | 13 | 4 | |
| 1964 | 23 | 7 | |
| 1965 | 41 | 7 | |
| 1966 | 31 | 7 | 6 |
| 1967 | 33 | 7 | 26 |
| 1968 | 36 | 8 | 30 |
| 1969 | 29 | 4 | 37 |
| 1970 | 28 | 5 | 48 |
| 1971 | 29 | 1 | 53 |
| 1972 | 20 | 2 | 52 |
| 1973 | 23 | 2 | 61 |
| 1974 | 25 | 1 | 55 |
| 1975 | 26 | 1 | 62 |
| 1976 | 34 | 1 | 64 |
| 1977 | 27 | 2 | 69 |
| 1978 | 25 | 1 | 62 |
| 1979 | 19 | 2 | 66 |
| 1980 | 24 | 1 | 64 |
| Total | 514 | 70 | 755 |

Note.—Launch totals through 1980 have been taken from table 14 of Soviet Space Programs: 1976–80, Pt. 1. p. 54.
Prepared for the Congressional Research Service by G. E. Perry.

## LAUNCH VEHICLES

In the Soviet Union as well as in the United States, the development of military long-range missiles was the essential source of most space launch vehicles until such time as space requirements for larger payloads began to exceed missile capabilities. Whereas the United States initially opted to develop the non-military Vanguard to orbit payloads for the International Geophysical Year (IGY), the Soviet Union, from the outset, took its original ICBM and applied it to space work for the flights from 1957 on. Even today, although with improved final stages, this vehicle is still in use in the Vostok, Soyuz and Molniya configurations and, with a successful launch total which surpassed 1,200 during 1987, far outstrips any other launch vehicle in the number launched.

The annual record of successful Soviet orbital and escape launches by basic first stage for the period 1957–1980 is presented in table 24.

TABLE 24.—RECORD OF SOVIET LAUNCHES BY BASIC FIRST STAGE: 1957–1980

| | A | B | C | D | E |
|---|---|---|---|---|---|
| Year: | | | | | |
| 1957 | 2 | | | | |
| 1958 | 1 | | | | |
| 1959 | 3 | | | | |

### TABLE 24.—RECORD OF SOVIET LAUNCHES BY BASIC FIRST STAGE: 1957–1980—Continued

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1960 | 3 | | | | |
| 1961 | 6 | | | | |
| 1962 | 13 | 7 | | | |
| 1963 | 13 | 4 | | | |
| 1964 | 22 | 7 | 1 | | |
| 1965 | 33 | 7 | 6 | 2 | |
| 1966 | 34 | 7 | | 1 | 2 |
| 1967 | 36 | 13 | 4 | 2 | 11 |
| 1968 | 41 | 16 | 6 | 4 | 7 |
| 1969 | 43 | 14 | 6 | 4 | 3 |
| 1970 | 43 | 18 | 10 | 4 | 6 |
| 1971 | 40 | 12 | 19 | 6 | 6 |
| 1972 | 47 | 12 | 13 | 1 | 1 |
| 1973 | 53 | 10 | 15 | 7 | 1 |
| 1974 | 49 | 6 | 17 | 6 | 3 |
| 1975 | 58 | 5 | 18 | 4 | 4 |
| 1976 | 54 | 4 | 28 | 5 | 8 |
| 1977 | 54 | 2 | 28 | 4 | 10 |
| 1978 | 59 | | 21 | 5 | 3 |
| 1979 | 60 | | 18 | 6 | 3 |
| 1980 | 54 | | 16 | 5 | 14 |
| Total | 821 | 144 | 226 | 66 | 82 |
| Grand total | | | | | 1,339 |

Note.—Launch totals through 1980 have been taken from table 15 of Soviet Space Programs: 1976–80, Pt. 1. pp. 57–59. Prepared for the Congressional Research Service by G.E. Perry.

Only after some years did the Soviet Union move down in size to use medium-range and intermediate-range missiles as the first stages for space launch vehicles. The medium-range missile is no longer used, but an improved ICBM has been adapted for space launches.

The first larger launch vehicle, dedicated solely to space launches, was introduced in 1965—the Proton. An even larger launch vehicle, called the "G" vehicle in the West and intended to support a piloted lunar exploration program, never flew successfully. This has been succeeded by the Energiya heavy-lift launch vehicle, which made its first test flight in 1987.

## SUPPORT SERVICES

### LAND-BASED SUPPORT

Space operations require extensive support from Earth in addition to that associated with the construction of spacecraft and launch vehicles and the launches themselves, including down range guidance and command, tracking and communications links. After the payload is in orbit, then tracking is useful for keeping informed about it and all other objects in space, and for commands to be sent to the payload and receipt of any data it gathers or observes.

The Soviet Union appears to have embarked upon its space program with minimal land-based support, relying on the long-distance propagation of shortwave radio transmissions to receive information when their spacecraft were below the horizons of Soviet territory. Optical observations were used whenever conditions were favorable and observers in Soviet bloc countries were encouraged to send their reports to Moscow.

Doppler tracking and S-band radars were used for orbit determination from the outset.

A network of seven ground stations at Yevpatoria, Tbilisi, Dzhusaly, Kolpashevo, Ulan-Ude, Ussuriyisk, and Petropavlovsk, stretching from eastern Europe across the whole of Asia, was established to support piloted spaceflight operations.

As time passed, further stations were added to receive data from meteorological satellites and for communicating through Molniya, Raduga and Gorizont satellites, and these will be discussed in volume 2 of this report.

Laser tracking of satellites equipped with special corner-reflectors is used for geodetic purposes.

The deep space tracking station is located at Yevpatoria in the Crimea and is analogous to NASA's deep-space tracking facility at Goldstone, California.

The flight control centers are situated at Yevpatoria and just outside Moscow at Kaliningrad, the latter being opened in time to support the joint Apollo-Soyuz mission in 1975.

### SEA-BASED SUPPORT

The network of ground stations proved insufficient for providing the necessary coverage as the durations and complexity of missions increased. Whereas the United States developed bilateral agreements with other nations to permit the establishment of support stations in all parts of the world, the Soviet Union, after relying on long-distance propagation of shortwave radio frequencies in the early days, chose to develop a sea-based support system. In December 1967, the science ships of the Soviet Academy of Sciences were listed as the *Dolinsk, Bezhitsa, Ristna, Aksay, Morzhovets, Kegostrov, Nevel, Borovichi,* and *Kosmonavt Vladimir Komarov.*[2] The latter operated as a dry cargo vessel for a short period before being converted to its space support role whereas the rest were all modified smaller merchant vessels.

Two newer and larger ships, the *Akademik Sergey Korolev* and the *Kosmonavt Yuri Gagarin* were introduced in the early seventies and four new vessels, former freighters of the *Vytegrales* class rebuilt as space associated research ships in Leningrad during 1977–78, were added to the fleet to replace the aging *Dolinsk, Bezhitsa, Ristna* and *Aksay.* The *Kosmonavt Vladislav Volkov* was the first to appear, followed in turn by the *Kosmonavt Pavel Belyayev,* the *Kosmonavt Georgiy Dobrovolskiy* and the *Kosmonavt Viktor Patsayev.*

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[2] Moscow Radio, 2200 GMT, November 26, 1967.

# CHAPTER 2—LAUNCH SITES

As already noted, the Soviets have three launch sites: Tyuratam (sometimes called Baikonur), Plesetsk, and Kapustin Yur. A U.S. Department of Defense (DOD) publication reported that each of the three cosmodromes is protected from external attack by surrounding networks of air defense, including interceptor bases and surface-to-air missile complexes.[1]

A summary of annual successful launch totals by site is given in table 25.

TABLE 25.—RECORD OF SOVIET LAUNCHES BY SITE: 1957–1987

| | Tyuratam | Kapustin Yar | Plesetsk |
|---|---|---|---|
| Year: | | | |
| 1957 | 2 | | |
| 1958 | 1 | | |
| 1959 | 3 | | |
| 1960 | 3 | | |
| 1961 | 6 | | |
| 1962 | 13 | 7 | |
| 1963 | 13 | 4 | |
| 1964 | 23 | 7 | |
| 1965 | 41 | 7 | |
| 1966 | 31 | 7 | 6 |
| 1967 | 33 | 7 | 26 |
| 1968 | 36 | 8 | 30 |
| 1969 | 29 | 4 | 37 |
| 1970 | 28 | 5 | 48 |
| 1971 | 29 | 1 | 53 |
| 1972 | 20 | 2 | 52 |
| 1973 | 23 | 2 | 61 |
| 1974 | 25 | 1 | 55 |
| 1975 | 26 | 1 | 62 |
| 1976 | 34 | 1 | 64 |
| 1977 | 27 | 2 | 69 |
| 1978 | 25 | 1 | 62 |
| 1979 | 19 | 2 | 66 |
| 1980 | 24 | 1 | 64 |
| 1981 | 38 | 1 | 59 |
| 1982 | 41 | 4 | 56 |
| 1983 | 32 | 4 | 62 |
| 1984 | 33 | 2 | 62 |
| 1985 | 35 | 1 | 62 |
| 1986 | 35 | | 56 |
| 1987 | 47 | 1 | 47 |
| Total | 775 | 83 | 1,159 |

Prepared for the Congressional Research Service by G.E. Perry.

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[1] U.S. Dept. of Defense. Soviet Military Power 1983. Washington, U.S. Govt. Print. Off., March 1983, p. 66.

## TYURATAM

The international flight of Soyuz T-6 to Salyut 7 in 1982 provided new details about the Baikonur cosmodrome. Seven French television, radio and newspaper correspondents were the first Western journalists to be allowed to visit the very secret site in Kazakhstan.[2] A few days before the launch the journalists, accompanied by representatives of the French National Space Studies Center (CNES) and of the Soviet Ministry of Foreign Affairs flew from Moscow to the cosmodrome in a little under 3 hours.

The new city of Leninsk, construction of which started at the same time as the cosmodrome in 1955, is about 10 km from the airport. It was built specially, on the site of the small village of Tyuratam, to provide housing for civil and military personnel of the cosmodrome and their families and accommodates workers from local industry and students at the new Aviation Institute. The population, in 1982, was around 50,000.

The city consists mainly of apartment buildings. The main street begins at a central square surrounded by official buildings and a hotel and leads directly to the cosmodrome entrance at the northern exit of the city. The "Cosmonaut" Hotel, which is used by the cosmonauts and their escort crews, is situated just short of the entrance to the cosmodrome, adjacent to a telecommunications station. It is totally isolated from the rest of the city, spreading out over 60 hectares of woods along the river. It is equipped with air-conditioned rooms, recreation rooms and sports facilities, such as tennis courts and a swimming pool. It also serves as a technical and medical center where the cosmonauts may train up to the last minute in a flight simulator.

The climate is harsh—very cold in winter (−30°C) and very hot in summer (40°C). The site was chosen for its remoteness and relatively clear skies—it averages 300 sunny days per year.

The cosmodrome spreads out over more than 100 km around its original site, some 35 km north of the city. The technical assembly complex (MIK) for booster rockets and spaceships was built in 1966. This is where crew members make their last-minute preparations (suiting-up) and the components of the booster rocket, Soyuz T and Progress spaceships are assembled. These are delivered by rail, three to four weeks before launch, from manufacturing plants situated "almost anywhere in the U.S.S.R." [3]

The small homes used by Korolev and Gagarin in 1961 are near the approach to the launch site for manned spaceships. The journalists could see, several kilometers away, a large manufacturing site with metal towers some 100 m tall, located near a very tall building which they took to be an assembly hall, and speculated that it might be the site for a new large booster rocket or reusable space shuttle.

Details of the preparation of the Soyuz 26 launch vehicle at the end of 1977 and the city of Leninsk were given in an article published nearly 4 years later.[4]

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[2] Langereux, P. Air and Cosmos, July 17, 1982, p. 57–60, 68.

[3] Ibid.

[4] Gor'kov, V. Moscow, Aviatsiya i Kosmonavtika, October 1981, p. 42–44.

The flight of the U.S. space shuttle STS-9 in December 1983 provided imagery of the Tyuratam area.[5] Application of photogrammetric techniques provided estimates of the dimensions of three of the larger buildings (220 x 190 x 23, 220 x 80 x 35 and 155 x 110 x 23 meters) and permitted the construction of a map of the area depicting a new 5 km long runway construction suitable for use by a reusable space shuttle.[6] A 20 km long track across the surrounding steppe extending from the runway in a direction close to the launch azimuth for piloted spaceflight could also be discerned. Existence of a "15,000 feet runway" for such a purpose was revealed to American representatives attending the Space Future Forum in Moscow at the beginning of October 1987.[7]

By 1984, U.S. reconnaissance satellites had photographed extensive construction work on new launch pads and support facilities for the anticipated Soviet space shuttle and heavy lift launch vehicle (HLLV), including a large assembly building, comparable in size to the vertical assembly building (VAB) at the Kennedy Space Center (KSC) in Florida. The piloted and automated HLLV developments all had coordinated designs enabling the same or similar propulsion hardware to be employed in the different programs. The large cryogenic rocket fuel storage areas were shown to be much larger than those at KSC now used for the U.S. space shuttle, but orginally constructed for the Saturn V Moon program.[8]

The entry under "Baikonur" in a 1985 encyclopedia[9] confirms the date of foundation as 1955 and gives the location as "in Kzyl-Orda Oblast, Kazakh SSR." It summarizes the main and auxiliary facilities and services, which are said to cover a large area and be inter-connected by roads and railways. Included in the main facilities are technical support positions, launch complexes and measuring stations. These are furnished with general technical and special technological equipment together with approach roads which allow for the reception, storage and assembly of launch vehicles and spacecraft, their testing, fueling of spacecraft and their mating with launch vehicles, their delivery to the launch pad, testing and fueling of launch vehicles, and guidance, launch and control of the operation of a launch vehicle and spacecraft during powered flight.

The auxiliary and service facilities include zones for storage of fuel components, plants producing liquid oxygen and nitrogen, power and water supplies, communication, television and other systems. Each type of launch vehicle has one or more technical support positions and launch complexes.

As the result of a written request from the Office of Technology Assessment (OTA) to Anatoliy Dobrynin, the Soviet Union's Ambassador to the United States, Dr. Balayan, vice chairman of the Intercosmos Council of the Soviet Academy of Sciences, produced a technical memorandum which was an official summary of Salyut space station activities, also giving information about the Baikonur cosmodrome and various support facilities.[10]

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[5] Aviation Week and Space Technology, January 9, 1984, p. 17.

[6] Thomson, G. H. Nature, October 18, 1984, p. 607.

[7] Aerospace Daily, October 7, 1987, p. 33.

[8] Aviation Week and Space Technology, March 12, 1984, p. 111.

[9] Kosmonavtika Entsiklopediya, Moscow, 1985, p. 42.

[10] U.S. Office of Technology Assessment. Salyut: Soviet Steps Toward Permanent Human Presence in Space, Appendix A. Washington, December 1983. OTA-TM-STI-14.

The launch structure for the Soyuz or A-class launch vehicle employs a launch system with releaseable supporting beams which accept the weight of the rocket. The rocket is suspended over the gas-deflecting trough with its tail portion several meters below the level of the platform. After ignition, the thrust of the engines increases. The launch vehicle begins to rise when the total thrust exceeds its weight and it is freed from the clamps of the launch support beams.

The special technical and launching complexes for the Proton or D-class launch vehicle are described in some detail in a Soviet brochure promoting their offer to launch payloads for foreign customers.[11] The main building of the technical complex is the integration and test facility in which assembly and mating of the Proton launch vehicle stages are carried out in the horizontal position using special jigs and trolleys. The jig used for the assembly of the first stage is said to be the most important. The central core is fixed on the jig so that it can be rotated about its longitudinal axis. One of the six side units, on its assembly trolley, is positioned underneath the central core and attached to it. The trolley is removed and the central core rotated through 60° and the next side unit is moved into position and attached. This process is continued until all six side units have been attached to the central core. The complete first stage is then removed from the jig by a bridge crane and transferred to the assembly mating trolley, where it is mated to the remaining stages. Assembly and integrated testing of the assembled launch vehicle takes place simultaneously with the preparation of the payload at the integration and test facility.

The launching complex consists of two pads separated by a distance of 600 meters. The launch vehicle is delivered to the launching complex by a flat-bed railcar. Its vertical positioning and installation on the launch pad is performed by the special crane of the launch facility. The D-vehicle, unlike the A-vehicle, is not suspended in the launcher system, but is installed directly on the supporting fixtures of the launch pad.

The lift-off maintenance phase is carried out with the aid of a rail-mounted mobile service tower which is removed to a safe distance prior to launch. The launching complex is completely free from cable and umbilical masts. Their role is performed by a special docking mechanism which, at the moment of lift-off, is raised to track the launch vehicle's motion for a fraction of a second before it is withdrawn by the pneumatic accelerators being firmly covered by steel armoured covers which, after closing, form the engine gaseous jet cutter. Lift-off is controlled from the command center situated 1.5 km from the launching complex.

Recent modifications to the launching complex, necessitated by its potential commercialization, include provision for replenishing with liquid oxygen on the launch pad, and new systems for supplying compressed gases to the booster and providing thermostatic control of the payload.

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[11] Soviet launcher PROTON has been used for launching the "Salyut" and "Soyuz" orbital station. Licensintorg, Moscow, (n.d.).

False-color Landsat imagery of the area from the U.S. company EOSAT has been published [12] as has black and white, 10 m resolution imagery from the French SPOT satellite.[13] The latter revealed the striped markings on the runway and paved overruns at either end. A large paved area, permitting exterior handling of hardware, adjoining one of the assembly buildings is also visible. A large launch pad with a triangular flame trench, thought to be associated with a heavy-lift vehicle and reusable space shuttle, can be seen in the area identified in the STS-9 imagery.

The Soviet desire to attract foreign customers for launch services through Glavkosmos has led to the opening up of the cosmodrome to potential clients. The first representatives of western business circles who were permitted to visit the cosmodrome were from the International Maritime Satellite Organization (INMARSAT) and British Aerospace during October 1987.[14] Representatives of Space Commerce Corporation of Houston, Texas, visited the cosmodrome in November 1987.[15]

## KAPUSTIN YAR

The entry in the 1985 encyclopedia [16] the date of the foundation of the Kapustin Yar cosmodrome as 1946, but does not give a location. The first Soviet ballistic and geophysical rockets were tested there, under the guidance of Sergey P Korolev, from 1948 through 1956. It is equipped with pads for launching Cosmos and Intercosmos satellites as well as the Vertical geophysical and scientific research sounding rockets. There are the usual technical support positions and stations used to measure the flight parameters of the launch vehicles in the powered phase of their missions.

In 1983, an article entitled "Kapustin Yar: A Look Through the Years," by special correspondent V. Gubarev, appeared in *Pravda*.[17] He writes that "the road to space began right here" immediately after the war. Conditions at that time were said to be unbelievably difficult—the bare steppe, no water and a shortage of food following the severe drought of 1946. By working for 18 hours a day they were able to launch the first ballistic rocket on 18 October 1947. A concrete memorial in the form of a rocket now marks the spot from which this launch took place and the road to the current launch pads runs past it. The workshops and drawing offices were of wooden construction and, gradually, roads and railway lines appeared. Eventually, through the use of irrigation, trees and grass were encouraged to grow and there is now a park in the center of the city.

Academician N. Pilyugin recalled that 13 rockets were launched during the months of October and November 1947. Academician A. Blagonravov was chairman of the State Commission for the launching of the first "academic" rockets and has described the competition between differing scientific disciplines to obtain launches for their experiments. By the end of the 1940s, animals were being flown in the nose cones of sounding rockets. Pairs of dogs, some of which flew more than once, were used for gathering data on the reaction of living organisms to rocket flight. They were provided with life-support systems and instrumented for recording their physiological functions. Some difficulties arose in connection with returning the dogs to Earth. Some were ejected at altitude and returned to Earth by parachute. Nine experiments were conducted with pressure suits.

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[12] National Geographic Magazine, October 1986, p. 422-423.
[13] Aviation Week and Space Technology, September 1, 1986, p. 42-43.
[14] Novosti Press Agency. London, U.S.S.R. Space Bulletin, SB21, October 21, 1987, p. 10.
[15] Flight International, December 12, 1987, p. 16.
[16] Kosmonavtika Entsiklopediya, op. cit., p. 155.
[17] Pravda, June 6, 1983, p. 3.

It was reported that many of the scientists and engineers who started at Kapustin Yar transferred to the Baikonur cosmodrome in Kazakhstan and that when a third cosmodrome was established at Plesetsk, at the beginning of the 1960s, it seemed that use of Kapustin Yar might be discontinued. However, with the launch of Intercosmos 1, on October 14, 1969, it gained a new lease on life. Guests from all the Intercosmos countries were invited to witness the launch, although the satellite's instrumentation was provided only by the U.S.S.R., the German Democratic Republic and Czechoslovakia. These included the presidents of the various academies of sciences, scientists and specialists from the countries participating in the Intercosmos program. The claim that "four times in the course of the year Kapustin Yar saluted the Intercosmos program with rocket launches"[18] may be attributed to journalistic license since Intercosmos 4 was launched on the first anniversary of the launch of Intercosmos 1.

As can be seen from table 25, the annual launch rate from Kapustin Yar is now only one or two per year with none at all in 1986. The C-vehicle has replaced the B-vehicle as the launcher and was used for the sub-scale spaceplane test flights in 1982–84.

## PLESETSK

The 1985 encyclopedia's entry for Plesetsk[19] is even more brief than that for Kapustin Yar, confining itself to listing Cosmos, Molniya and Meteor as the types of payloads orbited from there, repeating the standard phrase about technical support positions, launch complexes and measuring stations for determining flight parameters and giving the date of foundation as 1960.

The first public disclosure of the use and approximate location came from the Kettering Grammar School in England in 1966.[20] [21] However, the first Soviet acknowledgement of its existence came in two mentions in Gubarev's Pravda article on Kapustin Yar. This was followed, two weeks later, by his article on "Plesetsk—the Launching Point."[22] A Western journalist remarked that the

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[18] Ibid.

[19] Previous editions of this report have been self-contained, with each new version repeating all the historical information from past editions. As the years have progressed, it has become increasingly weighty to follow this practice. Therefore, beginning with this volume, only new developments will be described in detail. Fresh information is provided whenever it amplifies or amends that presented in earlier editions. Individuals interested in reading the previous editions can access them at U.S. Government depository libraries, which include most university libraries and libraries in major cities.

[20] Perry, G. E. Flight International. London, April 21, 1966, p. 670.

[21] Perry, G. E. Flight International. London, November 10, 1966, p. 817.

[22] Gubarev, V. Pravda, June 20, 1983, p. 3.

Soviet Union had made a major policy U-turn in its handling of the space program and for the first time in 26 years had permitted two of its launch sites to be described in the Soviet press.[23]

The article begins by citing two "fhying saucer" (UFO) reports and explaining them as sightings of a satellite launch from the Plesetsk cosmodrome. It goes on to report that Plesetsk is unusual in not being located in open steppe, but in taiga. At the time of Gubarev's visit, presumably for the nighttime launch of Intercosmos 8 on November 30, 1972, there was a lot of snow and the temperature was minus 30°C. The observation point was on the edge of a clearing in the forest, right next to the launch pad.

The most difficult feature confronting the constructors of the cosmodrome was the swampy nature of the terrain. The launching complexes were ready on schedule and the cosmodrome began operation in 1960, although it was six years before the first satellite was successfully launched from there. False-color imagery of the area has been published.[24]

Further details of the Plesetsk cosmodrome were revealed in another newspaper article.[25] It places the location in the Archangelsk region and points out that satellites under joint space programs involving, along with Soviet scientists, specialists of Sweden, Canada, USA, India and France, have been launched from there.

Pointing out that the launching of space rockets involves certain risks to settlements located up to hundreds of kilometers away from the cosmodrome, with spent stages falling to Earth possibly damaging structures and causing accidents, the article states that the active section of the launch trajectory should be over areas with small or no population at all and claims that the Archangelsk taiga satisfies this criterion.

There are a number of complexes, similar to the launching site for the Soyuz carrier rocket, intended for launching Molniya and Meteor satellites.[26] Launches of small and medium-size satellites, such as Cosmos and Intercosmos, are made from complexes named Raduga (Rainbow) and Voskhod (Ascent).[27] These do not employ the suspended launch system of the A-vehicle, but are installed directly on the launch pad. Servicing is from a 100 m rail-mounted turret with a foundation of some 200 sq m and a total weight of 450 tonnes. The turret was said to cover, like a bell, the starting device and the rocket itself during preparation for launching, ensuring the normal operation of the servicing personnel in any weather and at any time of day. The upper part houses a special hoisting gear for placing the launch vehicle in the vertical position. These complexes differ from others in that, should the need arise, payloads can be switched when the rocket is already on the starting device.[28]

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[23] Rich, Vera. Nature, London, June 30, 1983, p. 745.

[24] National Geographic, October 1986, pp. 440–441.

[25] Krasnaya Zvezda, August 29, 1987.

[26] Since 1982, most Meteor satellites have been launched by the F-2 and not the A-1 launch vehicle.

[27] There is a possibility of confusion in the use of these names which have been used for types of spacecraft, neither of which has been launched from Plesetsk. Raduga is a class of geosynchronous communications satellite and Voskhod was the name given to two piloted spacecraft which flew between the Vostok and Soyuz series.

In the design of the Raduga and Voskhod technical and launching complexes the equipment was unified to some degree. The technology of the preparation for launching is standard, despite the differences of the rockets. Both types can be prepared for flight on one and the same technical complex.

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[28] This degree of flexibility may account for the relatively short reaction time which has been observed when a replacement payload is orbited following point-failure of an operational satellite.

## CHAPTER 3—LAUNCH VEHICLES

The Soviet Union has a broad range of launch vehicles from the small C vehicle to the relatively large D, or Proton, launch vehicle. Most of the vehicles have two or more variants of the basic design. Table 26 presents the record of orbital and escape launches by launch vehicle variant from 1981 through September 30, 1987, with class sub-totals for the period 1957 through 1980.

TABLE 26.—RECORD OF LAUNCHES BY LAUNCH VEHICLE VARIANT: 1981–87

| Variant | 1957–80 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987[1] |
|---|---|---|---|---|---|---|---|---|
| A-1 | | 6 | 5 | 4 | | 1 | | |
| A-2 | | 41 | 43 | 42 | 44 | 40 | 36 | 43 |
| A-2e | | 14 | 11 | 11 | 11 | 16 | 14 | 4 |
| Subtotal | 830 | 61 | 59 | 57 | 55 | 57 | 50 | 47 |
| B-1 | 144 | | | | | | | |
| C-1 | 226 | 18 | 22 | 22 | 18 | 11 | 15 | 13 |
| D-1 | | 1 | 1 | 1 | | | 1 | 2 |
| D-1e | | 6 | 7 | 11 | 3 | 10 | 7 | 11 |
| Subtotal | 66 | 7 | 87 | 12 | 13 | 10 | 8 | 13 |
| F-1r | | | | | | | | |
| F-1m | | 8 | 8 | 2 | 4 | 5 | 5 | 6 |
| F-2 | | 4 | 4 | 5 | 7 | 12 | 11 | 11 |
| Subtotal | 73 | 12 | 12 | 7 | 11 | 17 | 16 | 17 |
| J-1 | | | | | | 2 | 2 | 5 |
| Total | 1,339 | 98 | 101 | 98 | 97 | 97 | 91 | 95 |

Note.—Launch totals through 1980 have been taken from table 15 of Soviet Space Programs: 1976–80, Pt. 1, pp. 57–59. Nine launches in 1980 have been reallocated to A–2 from F–2 based on new analysis.

Prepared for the Congressional Research Service by G.E. Perry.

The annual record of successful Soviet orbital and escape launches by basic first stage is presented in table 27. Of the 2,016 launches included in table 27, 1,216 are accounted for by use of the A-class launch vehicle.

TABLE 27.—RECORD OF SOVIET LAUNCHES BY BASIC FIRST STAGE: 1957–1987

| | A | B | C | D | F | J |
|---|---|---|---|---|---|---|
| Year: | | | | | | |
| 1957 | | | | | | |
| 1958 | 1 | | | | | |
| 1959 | 3 | | | | | |
| 1960 | 3 | | | | | |
| 1961 | 6 | | | | | |
| 1962 | 13 | 7 | | | | |
| 1963 | 13 | 4 | | | | |
| 1964 | 22 | 7 | 1 | | | |
| 1965 | 33 | 7 | 6 | 2 | | |
| 1966 | 34 | 7 | | 1 | 2 | |
| 1967 | 36 | 13 | 4 | 2 | 11 | |
| 1968 | 41 | 16 | 6 | 4 | 7 | |
| 1969 | 43 | 14 | 6 | 4 | 3 | |
| 1970 | 43 | 18 | 10 | 4 | 6 | |
| 1971 | 40 | 12 | 19 | 6 | 6 | |
| 1972 | 47 | 12 | 13 | 1 | 1 | |

TABLE 27.—RECORD OF SOVIET LAUNCHES BY BASIC FIRST STAGE: 1957–1987—Continued

| | A | B | C | D | F | J |
|---|---|---|---|---|---|---|
| 1973 | 53 | 10 | 15 | 7 | 1 | ........... |
| 1974 | 49 | 6 | 17 | 6 | 3 | ........... |
| 1975 | 58 | 5 | 18 | 4 | 4 | ........... |
| 1976 | 54 | 4 | 28 | 5 | 8 | ........... |
| 1977 | 54 | 2 | 28 | 4 | 10 | ........... |
| 1978 | 59 | ............ | 21 | 5 | 3 | ........... |
| 1979 | 60 | ............ | 18 | 6 | 3 | ........... |
| 1980 | 673 | ............ | 16 | 5 | 5 | ........... |
| 1981 | 61 | ............ | 18 | 7 | 12 | ........... |
| 1982 | 59 | ............ | 22 | 8 | 12 | ........... |
| 1983 | 57 | ............ | 22 | 12 | 7 | ........... |
| 1984 | 55 | ............ | 18 | 13 | 11 | ........... |
| 1985 | 57 | ............ | 11 | 10 | 17 | 2 |
| 1986 | 50 | ............ | 15 | 8 | 16 | 2 |
| 1987 | 47 | ............ | 13 | 13 | 17 | 5 |
| Total | 1,216 | 144 | 345 | 137 | 165 | 9 |
| Grand Total | | | | | | 2,016 |

Note.—Launch totals through 1980 have been taken from table 15 of Soviet Space Programs: 1976–80, Pt. 1. p. 57–59. Nine launches in 1980 have been reallocated to A–2 from F–2 based on new analysis.

Prepared for the Congressional Research Service by G.E. Perry.

## DESIGNATORS

Until quite recently the Soviets have not identified a specific vehicle for a given launch. For many years no names at all were given, but the smallest of all launch vehicles was displayed in the space exhibition at the Museum of Economic Achievement in Moscow bearing the name "Cosmos" and the basic launch vehicle, bearing the name "Vostok," was displayed publicly for the first time at the 1967 Paris Air Show. The North Atlantic Treaty Organization (NATO) allocated code names, such as Sapwood, Sandal, Skean and Scarp to missiles with recognizable configurations.

The U.S. Department of Defense (DOD) instituted its own system of identification by assigning them "SS" numbers and, when they were identified as space launch vehicles, gave the variants "SL" numbers in chronological order of their appearance. An "X" suffix was used to denote that a particular variant was still in the experimental phase.

In 1968, in the absence of anything better in the open literature, the late Dr. Charles Sheldon devised the system which has been used in previous editions of these reports.[1] The scheme assigns a capital letter to each basic first stage and then uses a number for the principal upper stage. A final stage is indicated by a small letter showing its capability such as e—escape, m—maneuvering and r—reentry. A disadvantage of this system is that the number and small letter suffixes do not necessarily represent the same hardware when applied to different basic stages. However, the advantage of grouping variants by their basic first stages outweighs this disadvantage.

With the greater openness of the DOD and the appearance of new Soviet launch vehicles there is a growing tendency to use the

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[1] Sheldon, C. S. The Soviet Space Program: A Growing Enterprise, TRW Space Log, no. 4, Winter 1968–69, pp. 2–23.

DOD's SL-system.[2] This report continues to use the Sheldon system. Table 28, which lists Sheldon and DOD designators side by side with the Glavkosmos names, is provided for the reader's convenience.

TABLE 28.—SOVIET SPACE LAUNCH VEHICLE DESIGNATIONS AND PAYLOAD CAPABILITIES

| Sheldon designator | U.S. DOD designator | Glavkosmos name | Payload to LEO (tonnes) |
|---|---|---|---|
| A-1 | SL-3 | Vostok | 6.3 |
| A-2 | SL-4 | Soyuz | 7.7 |
| A-2e | SL-6 | Molniya | [1] 2.1 |
| C-1 | SL-8 | Cosmos | 1.7 |
| D-1 | SL-13 | | 19.5 |
| D-1e | SL-12 | Proton | [2] 2.0 |
| F-1 | SL-11 | | 4.0 |
| F-2 | SL-14 | Cyclone | 5.5 |
| J-1 | SL-16 | | >15.0 |
| K | SL-X-17 | Energiya | 100.0 |

[1] to semi-synchronous orbit.

[2] To geosynchronous orbit.

Note.—Payload capabilities are to low Earth orbit (LEO) unless otherwise noted and are taken from Soviet Military Power 1987. U.S. Dept. of Defense. Washington, U.S. Govt. Print. Off., Mar. 1986. p. 49. The geosynchronous capability of the Proton is given in a Glavkosmos brochure, which quotes the LEO capability as 20.0.

Prepared for the Congressional Research Service by G.E. Perry.

## SOVIET ROCKET ENGINES

New information on the design of certain Soviet rocket engines appeared in the 1985 Encyclopedia of Cosmonautics.[3] Table 29, which presents this information, differs in some respects from table 17 of Soviet Space Programs: 1976-80.[4]

TABLE 29.—SOVIET SPACE-RELATED ROCKET ENGINES

| Engine | Design period | Chambers per engine | Chamber pressure (MPa) | Nozzle pressure (kPa) | Burn time (sec) | Isp (m/s) | | Oxidizer-fuel ratio | Thrust (kN) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ground | Vacuum | | Ground | Vacuum |
| RD-107 | 1954-57 | 4+2 | 5.4 | | 140 | 2,520 | 3,080 | 2.47 | 821 | 1,000 |
| RD-108 | 1954-57 | 4+4 | 5.1 | | 320 | 2,430 | 3,090 | 2.39 | 745 | 941 |
| RD-111 | 1959-62 | 4 | 7.85 | 59 | | 2,700 | 3,110 | | 1,407 | 1,628 |
| RD-119 | 1958-62 | 1 | 7.89 | 6.2 | 260 | | 3,450 | 1.5 | | 105 |
| RD-214 | 1952-57 | 4 | 4.36 | 69 | 140 | 2,255 | 2,590 | 3.97 | 635 | 730 |
| RD-216 | 1950-60 | 2 | 7.35 | 43 | 170 | 2,429 | 2,857 | | 1,469 | 1,728 |
| RD-219 | 1958-61 | 2 | 7.35 | 27 | 125 | | 2,875 | 2.5 | | 883 |
| RD-253 | 1961-65 | 1 | 14.7 | 61 | 130 | 2,795 | 3,100 | | 1,474 | 1,635 |
| RD-301 | mid-70s | 1 | 11.8 | 6 | [1] 750 | | 3,928 | 2.7 | | 98 |

[1] Capable of multiple starts.

Notes.—The only new engine is the RD-301, designed for the upper stages of launch vehicles and acceleration blocks. With liquid ammonia as fuel and liquid fluorine as oxidizer, it is described as the only fluorine liquid propellant rocket engine in the world to have undergone the full volume of bench tests, including official tests.

The SI unit of pressure is the pascal (Pa), 1 newton per sq. meter. One standard atmosphere is equivalent to 101.3 kilopascals (kPa).

To convert specific impulse in meters per sec to Isp measured in seconds, divide by 9.8.

To convert thrust in kilonewtons (kN) to thrust measured in metric tonnes weight, divide by 9.8.

Source: Kosmonavtika Entsiklopediya, Moscow, 1985. pp. 327-331.

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[2] Johnson, N. L. The Soviet Year in Space: 1986. Colorado Springs, Colo., Teledyne Brown Engineering, 1986.

[3] Kosmonavtika Entsiklopediya, op. cit., pp. 327-331.

[4] Soviet Space Programs: 1976-80, Pt. 1. Washington, U.S. Govt. Print. Off., Washington, 1982, pp. 67-69.

## LAUNCH FAILURES

The Soviet Union has been reluctant to admit to any failures in its space program. Launches which fail to reach orbit are rarely announced, but there are exceptions including the aborted Soyuz 18A and T-10A flights and the recent flight of the new heavy-lift launch vehicle, Energiya. Flights intended for the Moon or planets which failed to leave Earth parking-orbit were not acknowledged at one time. One result of Glasnost and the initiative to offer commercial launch services to foreign nations has been a new openness which acknowledged two failures of an improved fourth stage for the Proton launch vehicle in 1987.

A study by Phillip S. Clark estimates that about 100 Soviet failures may have taken place during 1957–1985.[5] In two tables, the first of which is based on a document in the Lyndon B. Johnson Library at Austin, Texas,[6] covering the period 1957 through the early part of 1964, Clark lists possible dates and missions, some of which can be confirmed from Soviet data. Table 30 combines these two tables and assigns probable launch vehicles to each possible failure. It can be seen that the greatest number of failures, half the total number, is for the A-class launch vehicle. However, expressed in terms of the total number of launch attempts for this class of vehicle (1,162 to the end of 1985), this represents a 96.3 percent success rate.

TABLE 30.—POSSIBLE SOVIET LAUNCH FAILURES

| | A | B | C | D | F | G | ? | Total |
|---|---|---|---|---|---|---|---|---|
| Year: | | | | | | | | |
| 1957 | | | | | | | | 0 |
| 1958 | 5 | | | | | | | 5 |
| 1959 | 3 | | | | | | | 3 |
| 1960 | 6 | | | | | | 1 | 7 |
| 1961 | 2 | 2 | | | | | | 4 |
| 1962 | | 1 | | | | | | 1 |
| 1963 | 4 | 1 | | | | | | 5 |
| 1964 | 6 | | | | | | 2 | 8 |
| 1965 | 4 | 1 | | | | | | 5 |
| 1966 | 6 | | 1 | 1 | | | | 8 |
| 1967 | 3 | | | 1 | | | | 4 |
| 1968 | 1 | 1 | 1 | 1 | | | | 4 |
| 1969 | | | | 4 | 2 | 1 | | 7 |
| 1970 | | | | 2 | | | | 2 |
| 1971 | 1 | | | | | 1 | | 2 |
| 1972 | | | | 1 | | 1 | | 2 |
| 1973 | | | | | 1 | | | 1 |
| 1974 | | | | | | | | 0 |
| 1975 | 1 | | 1 | 1 | | | | 3 |
| 1976 | | | | | | | | 0 |
| 1977 | | | | 1 | | | | 1 |
| 1978 | | | | 3 | | | | 3 |
| 1979 | | | | | | | | 0 |
| 1980 | | | | | | | 2 | 2 |
| 1981 | | | 2 | | | | | 2 |

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[5] Clark, P. S. Journal of the British Interplanetary Society, 1987, pp. 527–529.

[6] Peebles, C. Spaceflight, April 29, 1987, pp. 163–166.

TABLE 30.—POSSIBLE SOVIET LAUNCH FAILURES—Continued

| | A | B | C | D | F | G | ? | Total |
|---|---|---|---|---|---|---|---|---|
| 1982 | | | | 2 | | | | 2 |
| 1983 | 1 | | | | | | | 1 |
| 1984 | | | 1 | | | | | 1 |
| 1985 | | | | | | | 3 | 3 |
| Total | 43 | 6 | 6 | 17 | 3 | 3 | 8 | 86 |

Note.—The G-vehicle, or SL-15, was the Saturn V-class booster intended to support the landing of cosmonauts on the Moon.
Source: Clark, P. S. Soviet Launch Failures. Journal of the British Interplanetary Society, v. 40, 1987, p. 527–529.
Prepared for the Congressional Research Service by G.E. Perry.

## THE A-CLASS LAUNCH VEHICLES

Some of the figures published for the Soyuz launch vehicle in the 1985 encyclopedia[7] differ in some respects from those used previously. The maximum weight of the payload to LEO is said to be around 7 tonnes. Launch weight is approximately 310 tonnes and the length, together with the Soyuz spacecraft, is given as 39.3 meters. The maximum diameter, at the air vanes, is 10.3 meters. The first two stages are similar to those of the Vostok launch vehicle. The third stage has a four-chamber liquid-propellant rocket engine with one turbo-driven pump assembly, with four swiveling steering nozzles, developing a vacuum thrust of 298 kN. It has a length of 8.1 meters and a diameter of 2.66 meters. The flying time in powered flight is approximately 9 minutes. For Luna 4 through Luna 14, Zond 1 through Zond 3, Venera 1 through Venera 8 and some other early missions a fourth stage liquid-propellant rocket engine, with a vacuum thrust of 67 kN was used and, in this form, it is known as the Molniya launch vehicle.

A French journalist's report on preparations for the Soyuz T–6 mission gave the total weight as 315.5 tonnes, of which the liquid propellants accounted for 284 tonnes.[8]

## THE B–1 AND C–1 LAUNCH VEHICLES

The basic Cosmos launch vehicle described in the 1985 encyclopedia is the B–1 vehicle, which was retired from service in 1977. No new information was made available. The C–1 vehicle is implied in references to modifications of the Cosmos launch vehicle. One of these has an RD–216 engine in the first stage instead of the RD–214 and another has an RD–219 second stage engine instead of an RD- 119. Strictly speaking, the implication is that at least three variants exist instead of the two used in both the Sheldon and DOD classifications but re-classification to reflect the fine structure of B–1, B–2, C–1 and C–2, if all exist, must await further Soviet disclosures.[9]

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[7] Kosmonavtika Entsiklopediya, op. cit., p. 373.

[8] Langereux, P., op. cit.

[9] Kosmonavtika Entisiklopediya, op. cit., p. 202.

The C-vehicle was used for the four launches from Kapustin Yar of the sub-scale spaceplane described in chapter 5 of the first part of this report.

### THE D-CLASS LAUNCH VEHICLES

The first clear views of the Proton launch vehicle to be shown in the West were to be found in the television coverage of the launches of the two Vega spacecraft to Venus and Comet Halley at the end of 1984.[10] These included views of the interior of the flight control center and this gave the viewer the first sight of the booster on a black and white monitor adjacent to the large screen displaying the intended trajectory superimposed on a star atlas. Fears that this might be the only view one would have were quickly dispelled when the scene cut to an outdoor view of the white rocket, with its black conical nose-cap, standing vertically between lightning conductor masts and tall towers bearing banks of floodlights. Although the base of the rocket was obscured by a slight rise in the ground between the camera site and the launch pad, three of the cylindrical units, previously believed to be strap-on engines, could readily be seen. Flames and smoke billowed from the base of the rocket at the moment of ignition and the vehicle lifted-off almost immediately. The shock waves in the exhaust plume were clearly visible and, 12 seconds after lift-off, a black emission was seen in the center of the plume coming from the base of the rocket. As the rocket climbed away and began to pitch over it was possible to see the hexagonal array of burning engines end-on. From this it was not difficult to understand Western belief, current at that time, that a central core ignited at altitude.

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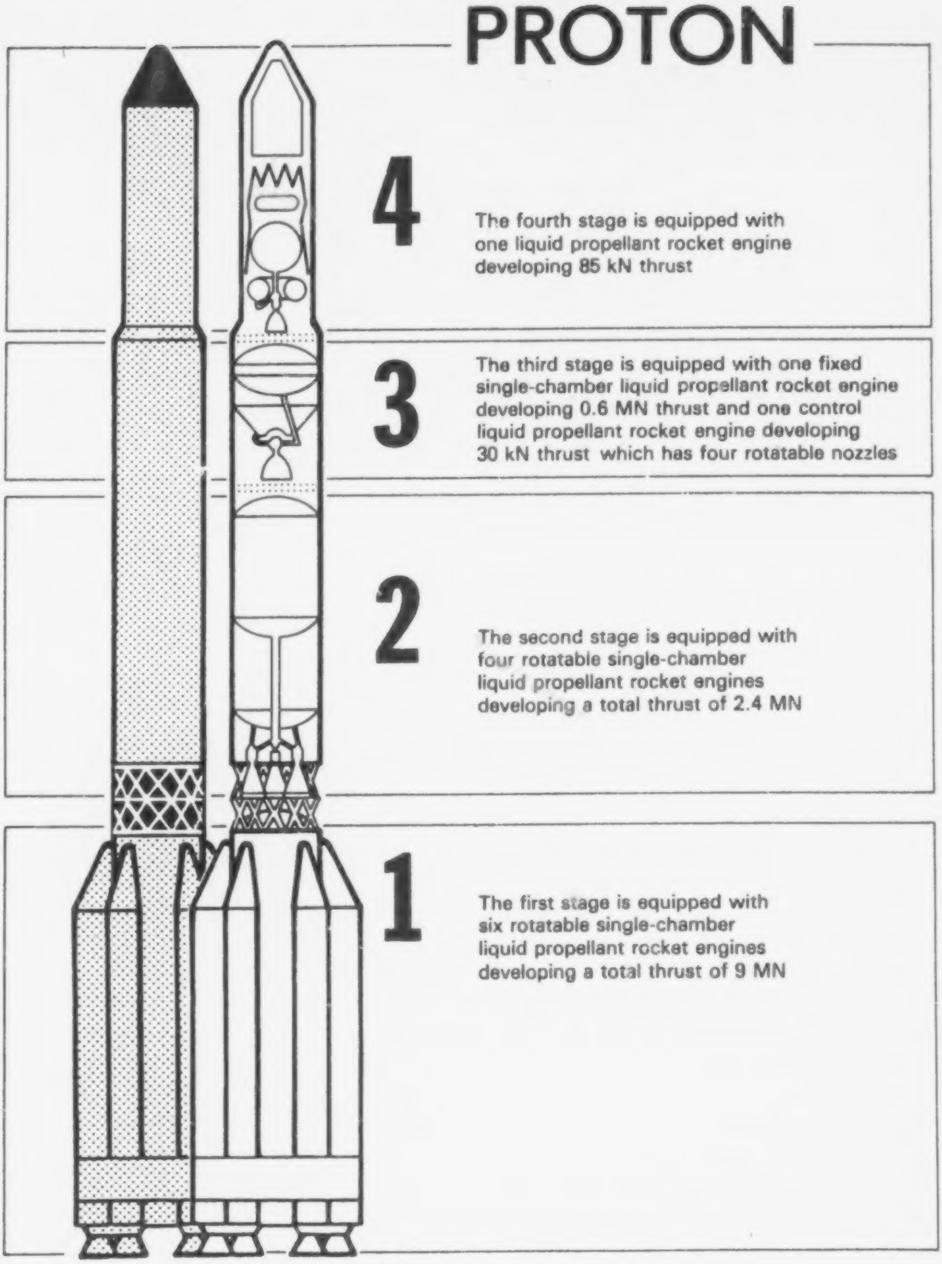
[10] Personal observation.

Figure 5



PROTON

The fourth stage is equipped with one liquid propellant rocket engine developing 85 kN thrust

The third stage is equipped with one fixed single-chamber liquid propellant rocket engine developing 0.6 MN thrust and one control liquid propellant rocket engine developing 30 kN thrust which has four rotatable nozzles

The second stage is equipped with four rotatable single-chamber liquid propellant rocket engines developing a total thrust of 2.4 MN

The first stage is equipped with six rotatable single-chamber liquid propellant rocket engines developing a total thrust of 9 MN

Detailed color plates illustrating the Proton launch vehicle in differing configurations, erected on the launch pad, on the flat-bed rail transporter and during the assembly of Salyut 7, were published in a large-format book in 1986.[11] Introducing the new book on Soviet television, Academician Avduyevskiy remarked,

> . . . In particular, it shows our beautiful Proton rocket, which has ensured the work of our cosmonauts on the Salyut stations—it put up the Salyut stations—and [launched probes to study] the whole of inter-planetary space and Venus and Mars. It is shown in a publication in such detail for the first time. It is important that it has been shown. . . . this Proton embodies the art of our 58 engineers who made such a perfect rocket which has been unequalled in the world for 20 years. . . . And it will serve for a long time yet and give an advantage to our space exploration, and the development of our space exploration, thanks to its qualities.[12]

Prior to the appearance of this book, the 1985 encyclopedia had carried entries for the Proton launch vehicle[13] and the Block "D," its fourth stage used for launching geosynchronous, semi-synchronous, and the later lunar and interplanetary payloads.[14] It was stated to be a two to four-stage launch vehicle which had been in operation since 1965. The two-stage version was used to launch the first three Proton satellites in 1965 and 1966. Proton 4 was launched by the three-stage version in 1968 but, before then, a four-stage version had been used to launch Zond 4 through Zond 6. This was also used to launch the remaining two Zonds, Lunas from Luna 15 onward, Venera 9 through Venera 16, Mars 2 through Mars 7, Raduga, Ekran and Gorizont spacecraft and some satellites of the Cosmos series.

The launch vehicle was described as being of a tandem design with the stages divided transversely. Six RD-253 engines are installed in the first stage producing a total thrust of 9 MN. Four single-chamber engines, each with a thrust of approximately 0.6 MN, are in installed in the second stage. The third stage employs another engine of the same type together with a steering engine, of approximately 30 kN thrust, possessing four swiveling chambers controlling the trajectory and attitude of this last stage. The overall length, minus the payload, was given as 44.3 meters and the maximum transverse dimension as 7.4 meters. Payload capability to LEO was said to be in excess of 20 tonnes.

This was the first official Soviet statement to call into question the Western concept of a central core with six strap-ons in the first stage with the core igniting at altitude.[15] It later became clear that the "strap-ons" were, in reality, engines and fuel tanks surrounding a central tank of oxidizer. The second stage is connected to the top of the oxidizer tank by a lattice structure.

The Block-D fourth stage is adapted for prolonged presence in space conditions and multiple re-starts of the propulsion unit. The maximum fueled weight is 17.3 tonnes. It is 5.5 meters long and 4 meters in diameter at the point of attachment to the third stage. The propellants are liquid oxygen and kerosene giving it a thrust of 85 kN with a specific impulse in excess of 300 seconds. The total operating time is greater than 600 seconds. Attitude control during unpowered flight is provided by self-contained propulsion units using nitrogen tetroxide (N2O4) and unsymmetrical dimethylhydrazine (UDMH). Sensors, switching and coordinating equipment and power supplies are installed on the Block-D and control is effected by the spacecraft's control system. Telemetry from the Block-D is relayed to ground stations via the spacecraft's transmitters. The encyclopedia entry also identified Cosmos 146 as launched by Proton with a Block-D fourth stage.

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[11] Kosmonavtika CCCP. Moscow, Machinostroyeniye, Planeta, 1986. pp. 112, 147, 148–149, 216, 349, 415, 426, 433, 439 and 479.

[12] Soviet television, 1800 GMT, February 19, 1986.

[13] Kosmonavtika Entsiklopediya, op. cit., p. 307.

[14] Ibid., p. 48.

[15] Soviet Space Programs: 1976–80, Pt. 1. Washington, U.S. Govt. Print. Off., 1982, pp. 95–98.

The information which was revealed piecemeal as described above was confirmed by brochures produced by Glavkosmos when Proton was offered as a commercial launcher to the rest of the world.[16] These showed a cutaway diagram of the complete four-stage version with captions faithfully reflecting data previously announced. The three- stage version was said to be aimed at injecting payloads of up to 20 tonnes weight into LEO at 51.6° inclination and 200 km altitude. Payload capabilities with the added fourth stage were given as 5.7 tonnes toward the Moon, 5.3 tonnes toward Venus, 4.6 tonnes toward Mars and 2 tonnes into geosynchronous orbit (GEO). In addition to the payloads mentioned above as having been orbited by the Proton launch vehicle it was noted that, since 1971, it had been used to place in orbit long-term orbital stations of the Salyut and Mir classes.

Data for the RD–253 rocket engine is the same as that given in table 29. The height of the engine is given as 2.72 meters with the maximum diameter of the combustion chamber as 1.5 meters. Weight of the non-fueled engine is 1,280 kg and 1,460 kg fueled.

Azimuthal guidance of the launch vehicle is provided by its control system which, in accordance with a pre-planned program, can correct the rocket to the desired angle during the initial phase of the flight.

Maximum static and dynamic g-loads for the spacecraft during its mission are provided as follows:

> at launch in the longitudinal direction 1.2 ± 0.8g within the frequency range of 10–15 Hz. in the lateral direction ± 3.0g within the frequency range of 5–7 Hz.
>
> during the mission in the longitudinal direction 4.0 g within the frequency range of 5–7 Hz. in the lateral direction ± 1.0 g within the frequency range of 5–7 Hz.
>
> at the moment of stage's separation in the longitudinal direction 1.25 ± 4.75g within the frequency range of 10–15 Hz. in the lateral direction ± 1.5g within the frequency range of 5–7 Hz.

In each case the axial and lateral g-loads can act simultaneously upon the spacecraft. Maximum vibrations affect the space vehicle during the first stage flight due to the acoustic field generated on the shroud external surface both by the engine and the boundary layer's turbulence.

The spacecraft-launch vehicle interface is provided by special connectors used for the transmission of commands from the launch vehicle and the telemetry from the spacecraft.

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[16] See section on Glavkosmos in volume 2 of this report.

Monitoring of the spacecraft's parameters during the orbit injection phase is carried out in the direct transmission mode during communication sessions with the launch vehicle provided within radio coverage zones and in memorizing modes with subsequent playback. Information from the spacecraft is transmitted in 8-bit parallel code at a rate up to 1 kilobit/sec via one channel of the launch vehicle's telemetry system.

With the particular aim of selling the Proton launch vehicle as a launcher of geosynchronous payloads, the brochure has a diagram outlining the procedure for injecting a satellite into such an orbit, making the point that injection is provided into any point of the geosynchronous orbit. It is gratifying to observe that the diagram bears a very close resemblance to that used in an earlier edition of this report.[17]

The 1987 International Space Future Forum in b c Moscow to celebrate the 30th anniversary of Sputnik produced a 36-page booklet on Proton giving further information.[18] The nose fairing, which has an inner coat of insulation to minimize acoustic load effects and internal and external coatings to ensure the required thermal characteristics, is jettisoned at T ± 370 sec at an altitude of 145.7 km, when the speed is 4.441 km/sec. Injection into LEO occurs approximately at T ± 600 sec.

Programmed maneuvers, which may last for 13 min, orient the longitudinal axis of the fourth stage in the direction necessary for departure into the transfer orbit. While in LEO, the fourth stage and attached payload are in passive flight with three axis orientation. Midway through this phase of the mission, at approximately T ± 50 min, the fourth stage is rolled 180° about its longitudinal axis to compensate for any drift of the control system gyroscopes, a process taking some 2.5 min. Free-flight coasting in the three-axis stabilized mode continues until approximately T ± 82 min when the fourth stage is ignited for the first time. This occurs at the first ascending node (northbound equator crossing) over the Gulf of Guinea. The duration of this first firing does not exceed 450 sec.

Programmed turns are made after shut-down to orient the longitudinal axis of the fourth stage and payload in the direction necessary for the second firing. A second gyro-compensation turn is made in the middle part of the free-flight, three-axis stabilized transfer orbit by rolling 180° around the longitudinal axis, again taking some 2.5 min. The free-flight coasting phase to apogee, which coincides with the descending node, lasts some 5.3 hours to approximately T + 6 hr 45 min. At this point the fourth stage ignites for the second time for up to 230 sec, applying a non-co-planar impulse to produce a GEO with injection accuracies of ± 20 min in orbital period, ± 1° in inclination and ±0.01 in eccentricity.

The command for separation is sent to the satellite at the instant of the second shut-down of the fourth stage and the satellite separates within 14.8 ± 0.05 sec after this. During that period of uncontrolled flight the angular rates of roll, pitch and yaw may reach 2°3° per sec. The relative linear rate of separation is 1.5 ± 0.3 m/s.

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[17] Soviet Space Programs: 1976–80, Pt. 3. Washington, U.S. Govt. Print. Off., 1985, p. 936.

[18] Soviet launch vehicle Proton for injecting satellite in geostationary orbit. Moscow, Vneshtoryizdat, Izd. No. 5644M, VTI zak.7287, (n.d.).

Communications sessions with the launch vehicle and payload begin at T−25 min and last until T + 23 min at the end of the programmed turns following injection into LEO. Further sessions are scheduled for T + 64 min until after the first firing of the fourth stage to achieve the transfer orbit, from T + 96 min to T + 119 min to monitor the second set of programmed turns, for 10 min at T + 173 min for a routine status check, from T + 239 min to T + 261 min to monitor the second roll maneuver, and from T + 318 min until the payload has separated from the fourth stage and is safely in orbit.

## EXPERIMENTAL FOURTH STAGE FAILURES

Cosmos 1817, launched at approximately 09:19 GMT on January 30, 1987, failed to leave LEO when the fourth stage failed to ignite at the first ascending node.[19] The successful launch, seven weeks later, of Raduga 20 suggested that the problem had been analyzed and overcome but, five weeks after that, on April 24, 1987, a second failure occurred when three Cosmos satellites, intended to be part of the test program for the GLONASS navigation system (analogous to the American GPS Navstar system), did not attain the desired orbits when the fourth stage shut down prematurely during its first burn and failed to ignite a second time at the apogee of the transfer orbit to circularize their orbits.[20] [21] S.F. Bogodyazht, director of the international department for Glavkosmos, initially denied that there had been a failure when asked for information by Space Commerce Corp., of Houston, Texas.[22] Arthur Dula, head of Space Commerce Corp. claimed that the reply was unacceptable and requested Glavkosmos to acknowledge the failure and describe details surrounding the accident.[23]

An explanation was offered by D. Poletayev, head of the launch department of Glavkosmos, at a meeting with Space Commerce Corp. representatives in Washington, D.C., on May 13. He said that the Soviets were using an experimental version of the fourth stage on some of its Proton boosters and that it had failed on two occasions this year. He went on to say that this version would not be used on Protons launching satellites for other countries.[24]

Some observers speculated that the experimental version of the fourth stage might employ cryogenic propellants,[25] but for the 100 kg additional payload that has been mentioned [26] that would not seem likely.

It is possible that an early use of the experimental fourth stage dates back to the change in the launch profile for triple GLONASS payloads at the end of 1985. Without definite pointers from the Soviets it will be extremely difficult, if not impossible, to differentiate between the use of the standard and improved fourth stages.

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[19] Aviation Week and Space Technology, February 9, 1987, p. 26.
[20] Aerospace Daily, April 29, 1987, p. 163.
[21] Aviation Week and Space Technology, May 4, 1987, p. 24.
[22] Aerospace Daily, May 1, 1987, pp. 178–179.
[23] Aviation Week and Space Technology, May 11, 1987, p. 34.
[24] Aviation Week and Space Technology, May 18, 1987, p. 22.
[25] Aerospace Daily, May 15, 1987, p. 259.
[26] Personal conversation with Art Dula, President of Space Commerce Corp., Houston, Texas (marketing agent for Proton in the U.S.).

## THE F-CLASS LAUNCH VEHICLES

The SS-9, NATO code-named Scarp, was paraded through Red Square for the first time in November 1967 and was described as having intercontinental and orbital capability.[27]

It was initially used for space launches in the F-1-r and F-1-m configurations for test flights in the FOBS and antisatellite (ASAT) programs. FOBS tests ended with Cosmos 433 in 1971 and there have been only three ASAT tests since 1980. These were the interceptions of Cosmos 1241 by Cosmos 1243 and Cosmos 1258 in 1981 and the interception of Cosmos 1375 by Cosmos 1379 on June 18 of the following year.

In the F-1-m configuration, it has continued to launch Radar Ocean Reconnaissance (RORSAT) and Electronic Ocean Reconnaissance (EORSAT) payloads for active and passive surveillance of Western fleet deployments and movements, a point emphasised by the DOD in support of its contention that the Soviet's ASAT capability is not being eroded by not having tested the warhead in space since 1982. As table 26 shows, there have been four or five launches of the F-1 annually since 1984.

It had been speculated that the 82.3° recoverable Cosmos satellites, announced as performing Earth resources missions, were launched by an improved version, designated F-2, which was introduced in mid-1977. However, Clark had expressed serious doubts based on his understanding that, without new second and third stages, the F-vehicle would lack the capability to orbit payloads in the 7-tonne category.[28]

It is now thought that the RORSATs and EORSATs are launched by the F-1-m (SL-11) and that the recoverable payloads are launched by the A-2 (SL-4). The improved F-2 (SL-14) launches heavy ELINT satellites, geodetic satellites, Meteor and oceanographic satellites and the new class of Cosmos satellites launched as sextuple payloads. All F-2 launches are made from Plesetsk at inclinations around 73.6° and 82.5°.

No photographs or film of an F-vehicle launch have been made available in the West. An inquiry made to a senior French scientist involved with the Oreol 3 project brought a reply that they did not have any photographs of the launch or preparations showing the launch vehicle.

The name "Tsyklon" (Cyclone) identified as part of the SL-11/ SL- 14 class of medium booster, appeared in 1987.[29] This was the result of a Glavkosmos briefing which offered Tsyklon as a commercial launch vehicle for 4-tonne payloads into circular orbits at 200 km altitude. It was described as a 3-stage vehicle fueled by UDMH with $N^{T2}2O_4$ as oxidizer. A model was displayed at the Space Future Forum in Moscow and the caption to a photograph of the model in a trade magazine gave the overall height as 39.27 meters.[30]

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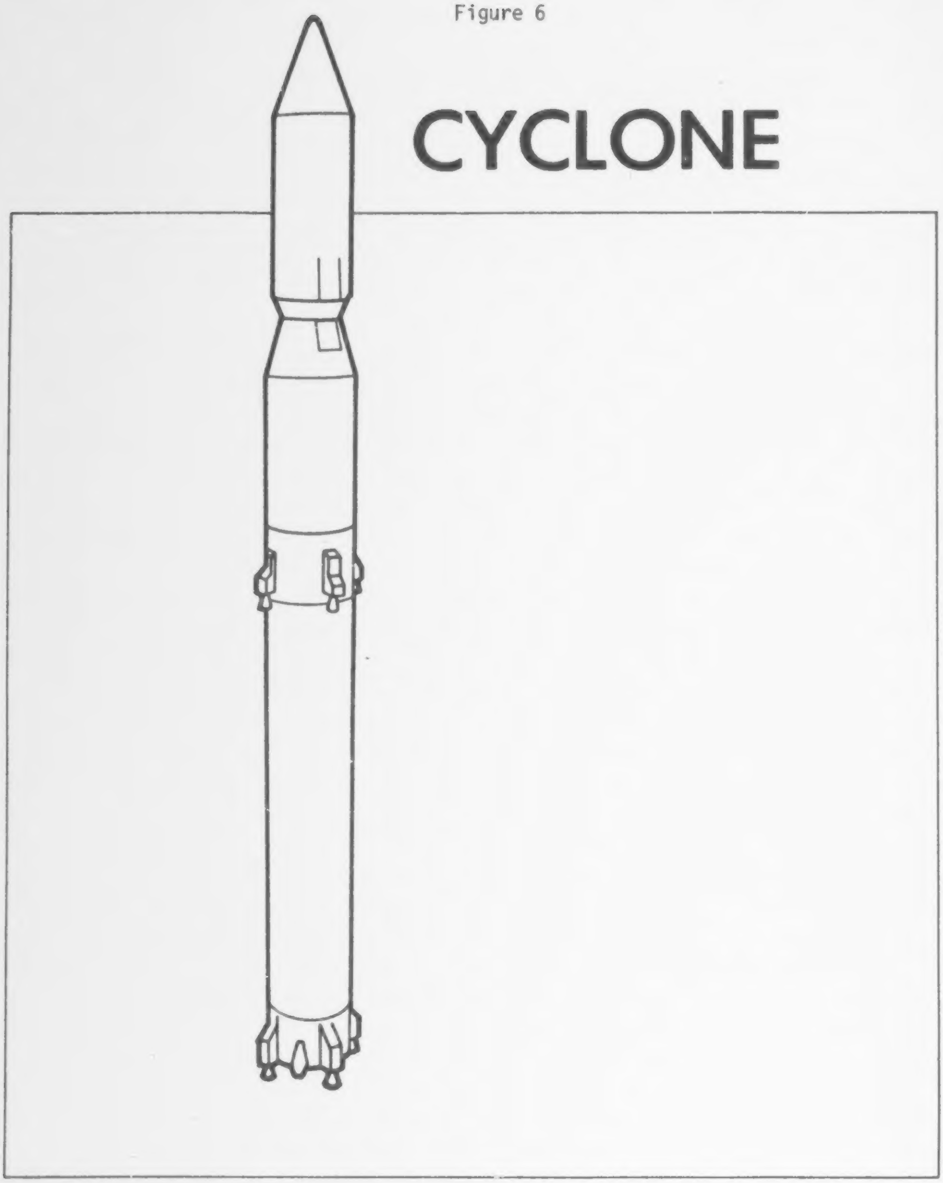
[27] TASS, 0710 GMT, November 7, 1967.

[28] Soviet Space Programs: 1976-80, Pt. 1. Washington, U.S. Govt. Print. Off., 1982, pp. 112-113.

[29] Aviation Week and Space Technology, June 1, 1987, p. 13.

[30] Aviation Week and Space Technology, October 12, 1987, pp. 26-27.

Figure 6



### THE J-VEHICLE

This was the first totally new launch vehicle to appear since Proton back in 1965. In 1979, when discussing the appearance of a new launch vehicle, now known as the F–2, Sheldon indicated that he would call the next completely new vehicle "J" having tentatively used "h" in speculating on the use of high energy propellants.[31]

Mention of a new medium-lift launch vehicle (MLLV) was made in the DOD's 1983 edition of Soviet Military Power which, in discussing the new launch facilities being built at Tyuratam to handle new generations of Soviet launch vehicles which would move from the developmental to the operational stage in the latter half of the decade, referred to "another somewhat smaller expendable booster." [32] A diagram comparing new U.S. and Soviet space launch vehicles estimated its payload capability as 13 tonnes to LEO, less than that of the D-vehicle, but approximately twice that of the A-vehicle.[33]

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[31] Sheldon, C.S., private communication to G.E. Perry, January 12, 1979.

A new Soviet launch vehicle, "comparable in size with the USAF Titan 3D" was reported to be on the launch pad at Tyuratam, being prepared for its first flight, at the beginning of 1984.[34] It was said to employ some of the same booster stage hardware used in the much larger Saturn V-class launch vehicle, which was also on a pad awaiting its first launch. Analysts said that the smaller vehicle was much closer to a first launch than the larger one and could be used later to launch a piloted winged spaceplane that had already flown three times in an automated sub-scale mode.[35]

This assessment was repeated in the 1984 edition of Soviet Military Power, which revised the payload capability to something in excess of 15 tonnes and depicted a reusable spaceplane, under development, as one of its possible payloads.[36] The new MLLV was said to be "evidently designed for high launch rates." [37] An artist's impression shows the new MLLV and the new heavy-lift launch vehicle (HLLV) erected on launch pads in the background as a Soviet space shuttle lifts-off.[38]

The three new launchers were reported to have coordinated designs to enable the same or similar propulsion stages to be used in all three programs and the Soviets were said to be "on the verge of flying liquid oxygen and hydrogen high-energy propulsion stages." [39]

One analyst speculated that the first stage of the MLLV is also used as a strap-on booster for the two larger launch vehicles and might also employ liquid oxygen/liquid hydrogen as propellants.[40]

On June 21, 1985, U.S. Space Command's Space Surveillance Center catalogued three fragments in orbits with inclinations close to 64.5° and with periods of less than 90 minutes from which they decayed within a week. These were never acknowledged by the Soviets although they were shown to be consistent with a launch from Tyuratam on June 21.[41] Western analysts, on the alert for the appearance of the new MLLV, had entertained thoughts that Cosmos 1603 and Cosmos 1656, which had entered 102 min orbits at 71° inclination after maneuvering from a 51.6° parking orbit via an intermediate orbit at 66.6°, might have used such a vehicle, despite the obvious pointers to a Proton launch provided by the initial parking orbits. These fragments were much more promising in that the inclination was close to those chosen for the flight tests of all new vehicles launched from Tyuratam.[42]

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[32] U.S. Dept. of Defense. Soviet Military Power 1983. Washington, U.S. Govt. Print. Off., March 1983, p. 66.

[33] Ibid., p. 68.

[34] Aviation Week and Space Technology, January 9, 1984, p. 15.

[35] Ibid.

[36] U.S. Dept. of Defense. Soviet Military Power 1984. Washington, U.S. Govt. Print. Off., April 1984, p. 44.

[37] Ibid., p. 45.

[38] Ibid., pp. 102-103.

[39] Aviation Week and Space Technology, March 12, 1984, p. 111.

[40] Parfitt, J. Spaceflight, November 1984, p. 410.

[41] The Royal Aircraft Establishment Table of Earth Satellites 1957-1986. London, 1987. p. 834.

When Cosmos 1697 went directly into the 102 minutes, 71° orbit four months later it was not unreasonable to suspect that it had been launched by the SL-X-16, also to be called the J-1. Cosmos 1714, at the end of the year, was intended for a similar orbit but was stranded in the transfer orbit when an engine failed to fire at apogee and circularize the orbit.

Optical observations by the Kettering Group revealed that the rocket of Cosmos 1697 was at least a stellar magnitude brighter than the payload, whereas payloads and rockets of Cosmos 1603 and Cosmos 1656 had been of equal brightness. This led them to the conclusion that Cosmos 1697 rocket was larger than the earlier two and prompted them to speculate that it was a test of a new launch vehicle.[43] Their observations of Cosmos 1714, at stellar magnitude −1 convinced them that it remained attached to the rocket body.[44]

The MLLV was designated SL-X-16 in a diagram in the 1986 edition of Soviet Military Power, reproduced as figure 7.[45] The latest edition points out that the payload capability in excess of 15 tonnes "fills a gap in the [Soviet's] current space launch vehicle inventory for an economical means of launching medium-weight payloads." [46] It went on to report that the SL-X-16 had been flight-tested, placing at least three payloads into orbit, and would soon be fully operational.[47]

Flights believed to have been launched by the J-1 are listed in table 31.

TABLE 31.—J-VEHICLE LAUNCHES: 1985–1987 [1]

| Date and name | Inclination (degrees) | Period (min) | Perigee (km) | Apogee (km) | Fragments |
|---|---|---|---|---|---|
| October 22, 1985, Cosmos 1697 | 71.0 | 102.0 | 849 | 854 | C-F |
| December 28, 1985, Cosmos 1714 | 71.0 | 94.7 | 164 | 843 | B-G |
| July 30, 1986, Cosmos 1767 | 64.9 | 88.5 | 197 | 205 | C-F |
| October 22, 1986, Cosmos 1786 | 64.9 | 113.3 | 190 | 2565 | C-F |
| February 14, 1987, Cosmos 1820 | 64.8 | 88.8 | 179 | 250 | C-E |
| March 18, 1987, Cosmos 1833 | 71.0 | 102.0 | 849 | 852 | C-F |
| May 13, 1987, Cosmos 1844 | 71.0 | 102.0 | 849 | 853 | C-F |
| August 1, 1987, Cosmos 1871 | 97.1 | 88.3 | 177 | 199 | - |
| August 28, 1987, Cosmos 1873 | 64.8 | 88.8 | 178 | 248 | - |

[1] Does not include June 21, 1985 "launch." See footnote 72.

Prepared for the Congressional Research Service by G.E. Perry.

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[42] The fragments were given an international designation by NORAD, but this report does not count the "launch" in its tabular statistics since either it was a suborbital test that accidentally put fragments in orbit, or was an unsuccessful attempt to launch a payload.

[43] White, M. Kettering Group Tech Memo: MW8601, October 1986. p. 4.

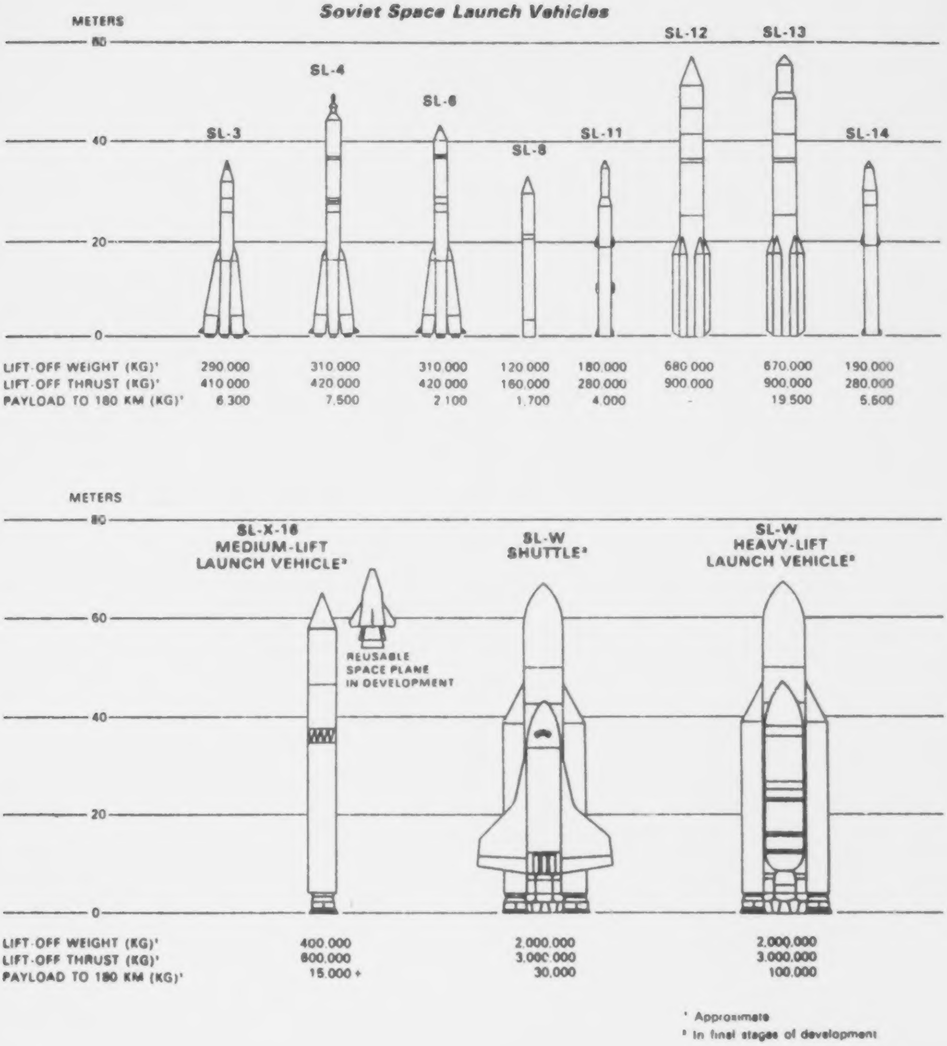
[44] Ibid., p. 3.

[45] U.S. Dept. of Defense. Soviet Military Power 1986. Washington, U.S. Govt. Print. Off., March 1986. p. 49.

[46] U.S. Dept. of Defense. Soviet Military Power 1987. Washington, U.S. Govt. Print. Off., March 1987. p. 54.

[47] Ibid.

FIGURE 7.



| | SL-3 | SL-4 | SL-6 | SL-8 | SL-11 | SL-12 | SL-13 | SL-14 |
|---|---|---|---|---|---|---|---|---|
| LIFT-OFF WEIGHT (KG)[1] | 290.000 | 310.000 | 310.000 | 120.000 | 180.000 | 680.000 | 670.000 | 190.000 |
| LIFT-OFF THRUST (KG)[1] | 410.000 | 420.000 | 420.000 | 160.000 | 280.000 | 900.000 | 900.000 | 280.000 |
| PAYLOAD TO 180 KM (KG)[1] | 6.300 | 7.500 | 2.100 | 1.700 | 4.000 | - | 19.500 | 5.600 |

| | SL-X-16 MEDIUM-LIFT LAUNCH VEHICLE[2] | SL-W SHUTTLE[2] | SL-W HEAVY-LIFT LAUNCH VEHICLE[2] |
|---|---|---|---|
| LIFT-OFF WEIGHT (KG)[1] | 400.000 | 2.000.000 | 2.000.000 |
| LIFT-OFF THRUST (KG)[1] | 600.000 | 3.000.000 | 3.000.000 |
| PAYLOAD TO 180 KM (KG)[1] | 15.000 + | 30.000 | 100.000 |

[1] Approximate

[2] In final stages of development

In reply to an inquiry, the U.S. Defense Intelligence Agency (DIA) strongly hinted that the unannounced event and two Cosmos missions in 1985 were tests of the SL–X–16.[48]

Two launches in 1986 exhibited new variations. Cosmos 1767 flew at a 64.9° inclination at a height which suggested to some analysts that it was a photoreconnaissance payload. However, it made no in-orbit maneuvers and decayed naturally over the South Indian Ocean after 17.5 days. The slow rate of decay suggested that it was quite dense, although visual observations by the Kettering Group showed it to be of the same stellar magnitude as a standard recoverable photographic reconnaissance Cosmos satellite.

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[48] Letter to C. P. Vick from DIA Public Affairs, June 11, 1986.

Cosmos 1786, at the same inclination, had an otherwise unique orbit. If an apogee firing to circularize the orbit was planned and failed it would have still been a unique orbit. Nicholas Johnson draws attention to the fact that these two satellites and the unannounced event of 1985 were all launched at around the same time of day (as was Cosmos 1873 in the following year) and offers the suggestion that they were merely flight tests, unrelated to any specific program.[49]

Lieutenant General Perroots, Director of DIA, stated at a press conference in Washington, D.C., in November 1987, that "the SL-16 became operational about three months ago." [50] This would imply that the 10-tonne Cosmos 1871, in retrograde orbit, was the first operational launch as that far exceeds the retrograde-orbit payload capability of the A-1 launch vehicle, the only Soviet launch vehicle to have been used for that purpose prior to that time.

## The K-Class Launch Vehicle: Energiya

Following the Sheldon system, this Saturn V-class heavy-lift launch vehicle (HLLV) takes the designation K. Sheldon would quip that the G, for the large booster developed in the sixties to land cosmonauts on the Moon and which, after several launch attempt failures was abandoned, stood for "giant." In a similar vein, K could be taken to indicate "king-size"!

DOD's SL-W designator was not very helpful, lacking a numeral, possibly because of the uncertainty of which version, with or without a space shuttle orbiter, would appear first. Even the X-designator, indicating that it was in the experimental stage, was not employed. DOD's booklet "The Soviet Space Challenge" employs a standard SL-X-17 designation for the first time.[51]

In 1980 it was reported in the West that work had resumed on a Saturn V-class vehicle.[52] The facilities had been mothballed after three attempts with the G-vehicle had failed in the late 1960s.[53] The forecast that the work "could result in a launch attempt as early as 1983" [54] was far too optimistic. The first edition of Soviet Military Power, reporting the development, cited its capability to launch heavy payloads into orbit, including very large permanently occupied space stations.[55] A payload capability to LEO of between 175 and 210 tonnes, some 50 per cent greater than the U.S. Saturn V Moon-rocket, was linked to a possible first test flight of the new HLLV in 1983.[56]

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[49] Johnson, N. L. The Soviet Year in Space: 1986. Colorado Springs, Colo., Teledyne Brown Engineering, 1987. p. 72.

[50] Aerospace Daily, November 25, 1987, p. 299.

[51] U.S. Dept. of Defense. The Soviet Space Challenge. Washington, U.S. Govt. Print. Off., November 1987. pp. 4, 13, 14.

[52] Aviation Week and Space Technology, June 16, 1980, pp. 26–27.

[53] Aviation Week and Space Technology, April 9, 1973, p. 21.

[54] Ibid.

[55] U.S. Dept. of Defense. Soviet Military Power. Washington, U.S. Govt. Print. Off., September 1981, pp. 79–80.

[56] Aviation Week and Space Technology, June 14, 1982, p. 19.

The 1983 edition of Soviet Military Power expressed the payload capability of the new HLLV as at least 6 to 7 times that of the U.S. space shuttle.[57] It estimated that the HLLV would move from the developmental to operational stage in the latter half of the 1980s.[58] An accompanying diagram depicted the HLLV in two versions; one with two strap-ons and a delta-winged vehicle attached to the side of the core and the other with 2-3 strap-ons attached to the core and an upper stage mounted on top of the core. Payload capabilities to LEO were given as 60 tonnes and 130-150 tonnes respectively.[59]

The first of the 100-meter tall HLLVs was reported to be on the launch pad at Tyuratam in October 1983, shrouded in camouflage nets to prevent U.S. reconnaissance satellites from taking detailed pictures of it.[60]

The diagram in DOD's 1984 Soviet Military Power was a revision of the previous year's and showed the winged vehicle looking much more like the U.S. space shuttle. The payload capacity of this version was increased to 96 tonnes + 30 tonnes shuttle payload capacity. The caption to the other version postulated 6 or more strap-ons and set the payload capability at 150 tonnes.[61] It was claimed that the Soviet shuttle "differs from the U.S. shuttle only in the respect that the main engines are not on the orbiter." [62] The 150-tonne payload capability was said to be "about 5 times the maximum U.S. capability." [63] An artist's impression showing the MLLV and HLLV in the background of a shuttle lift-off was also provided.[64]

In March 1984, the Soviets were said to be "on the verge of flying liquid oxygen and hydrogen high-energy propulsion stages." [65] Basic weight calculations based on estimated fuel tank volumes and propellant densities supported this contention.[66]

The HLLV was designated SL-W in both versions in a diagram in the 1986 edition of Soviet Military Power, reproduced as figure 2.[67] The shuttle payload to LEO was still estimated as 30 tonnes but the weight of the shuttle itself was omitted. The HLLV was shown in a configuration very much like that of the first Energiya when it appeared it 1987 (see below) but the payload capability to LEO was reduced to 100 tonnes. The caption to an artist's impression showing the shuttle mated to the HLLV on the launch pad contained the phrase "soon-to-be-tested." [68]

The 1987 edition of Soviet Military Power used the same drawings and artist's impression as the previous year's but changed the note for the HLLV from "in final stages of development" [69] to "in flight test" [70] Its payload capability to LEO was revised to something in excess of 100 tonnes.[71] The text speculated that launch pad compatibility testing of an orbiter attached to the SL-W vehicle might have already taken place and that a launch could come in 1987 or 1988.[72]

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[57] Soviet Military Power 1983, op. cit., p. 65.

[58] Ibid., p. 66.

[59] Ibid., p. 68.

[60] Aviation Week and Space Technology, October 31, 1983, p. 17.

[61] Soviet Military Power 1984, op. cit., p. 44.

[62] Ibid., p. 45.

[63] Ibid., p. 46.

[64] Ibid., pp. 102-103.

[65] Aviation Week and Space Technology, March 12, 1984, op. cit.

[66] Parfitt, J. op. cit., pp. 410, 412.

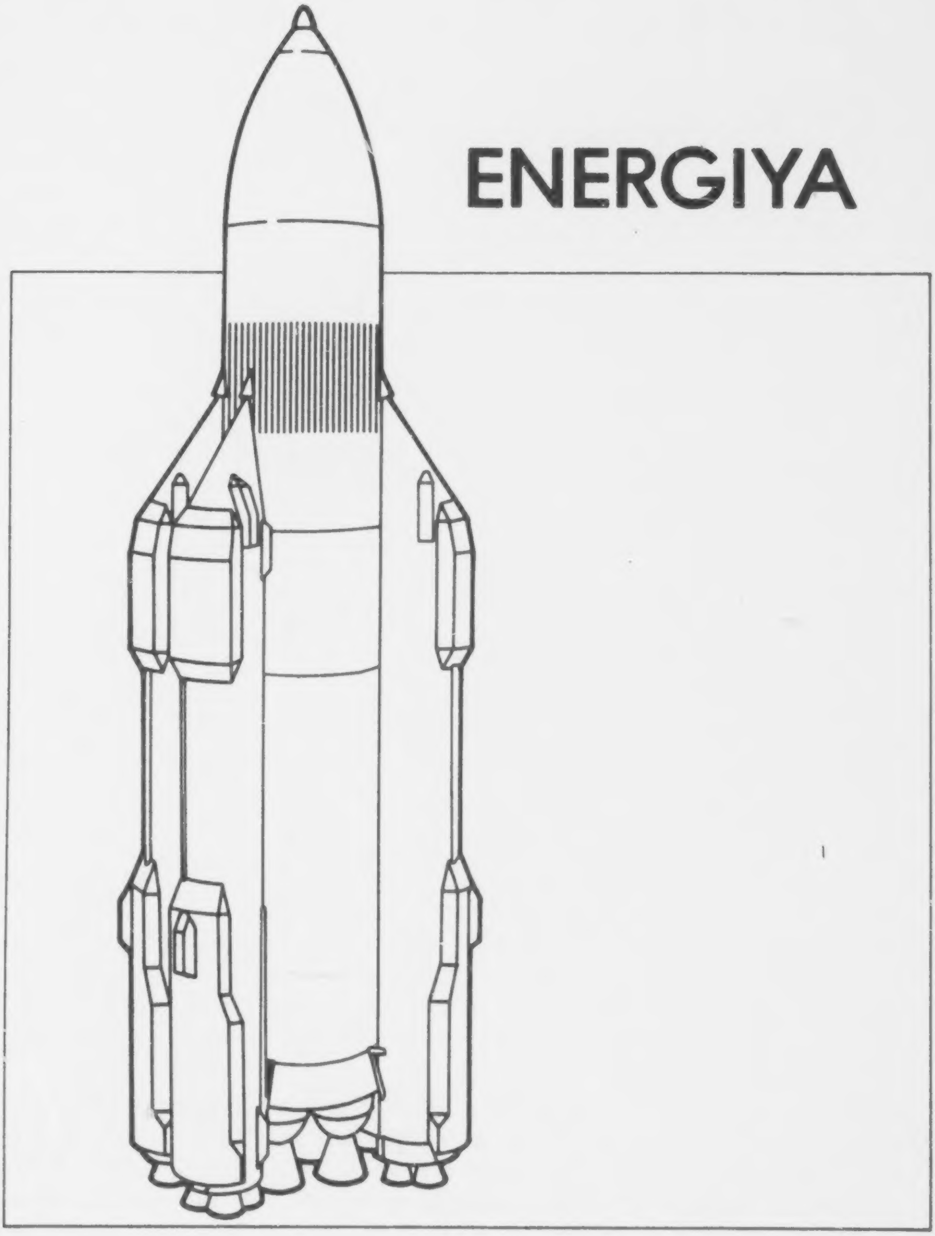
[67] Soviet Military Power 1986, op. cit., p. 49.

[68] Ibid., pp. 50-51.

[69] Ibid., p. 49.

[70] U.S. Dept. of Defense. Soviet Military Power 1987. Washington, U.S. Govt. Print. Off., March 1987. p. 56.

FIGURE 8



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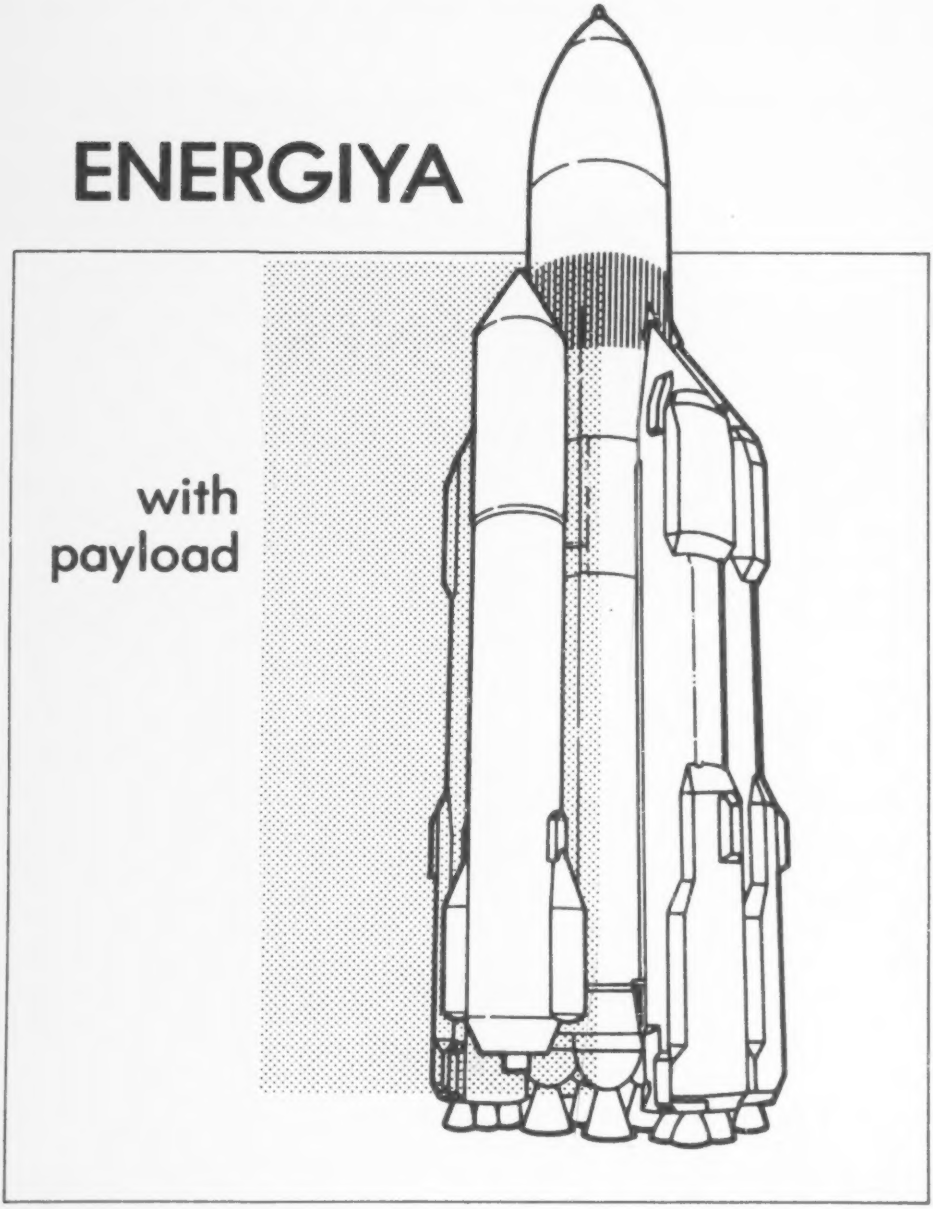
[71] Ibid.
[72] Ibid., p. 54.

FIGURE 9



A flight readiness firing consisting of a live countdown and static firing, lasting several seconds, was reported in March 1987, but no indication was given of the date when it took place.[73] The firing involved the large core stage and at least four liquid-fuel strap-on boosters arranged to allow placement of the Soviet shuttle orbiter or an automated cargo pod on the side of the vehicle.[74] The prediction for an automated flight by midsummer soon proved to be correct.

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[73] Aviation Week and Space Technology, March 16, 1987, pp. 20–21.

General Secretary Gorbachev visited Leninsk and the Baikonur cosmodrome from May 11–13, 1987. The report of his visit stated that the Space Center was preparing for a launch of a new all-purpose carrier rocket capable of delivering to LEO both reusable ships and large-scale research and commercial craft, including modules for orbiting space laboratories.[75]

News of the launch was delayed until the following day [76] and gave the time of launch, from the Baikonur cosmodrome, as 1730 GMT on May 15. The two-stage multi-purpose launch vehicle was said to have a mass at launch in excess of 2,000 tonnes and be capable of orbiting a payload of more than 100 tonnes. The announcement went on to say that the first-stage engines, after they had ceased firing, separated and landed in Soviet territory as planned. The second stage followed the flight plan precisely and delivered the payload, a full-size and weight mock-up of a satellite, to the calculated position and at that time separated from the payload and fell into the pre-planned area of the Pacific Ocean. Apparently, the payload should have injected itself into orbit by means of its own engine but, because of a malfunction of its onboard systems, failed to do so and also fell into the Pacific. The payload was observed as "an "intense' hot object for an unusually long period of time" by U.S. early warning satellites.[77]

Although the mission was something less than a success since the payload did not achieve orbit, the launch announcement claimed that the "launch and flight of Energiya had demonstrated the soundness of the concept and the technology, and the high reliability of its design, the engines of both stages and the control systems. The equipment and apparatus of the automated control of the launching complex had functioned normally. The aims and objectives of the first launching have been fully met."

The unprecedented openness surrounding this launch continued with the release of television coverage of the launch preparations and the nighttime launch itself. Viewers of the evening news bulletins of ITN and the BBC in the United Kingdom were treated to a brief daylight glimpse of the vehicle on the launch pad, taken from the side away from the dummy payload, and the burst of flame and smoke as the vehicle climbed clear of the large towers flanking the launch pad. Examination of a video-recording revealed a black, conical shape peeping over the top of one of the strap-ons. It subsequently transpired that a full length feature, running for nearly 10 minutes, had been transmitted from the Soviet Union, but that Saturday night program time, always reduced in comparison with mid-week news bulletins, was competing for coverage of the run-up to the General Election and the afternoon's football Cup Final. It opened with a shot of an automobile and pulled wide to reveal that it was at the base of a large flame pit. Descriptive extracts from special correspondent, Aleksandr Tikhomirov, follow.[78]

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[74] Ibid.

[75] Moscow Home Service, 1400 GMT, May 13, 1987.

[76] TASS, 1555 and 1604 GMT, May 16, 1987.

[77] Aviation Week and Space Technology, May 25, 1987, pp. 18–19.

> We took this shot at the beginning of this week, so that you could better understand the scale of the work. . . . This launch pad can be seen tens of kilometers away in the Baikonur steppe . . . each of the eight engines had passed captive and firing control tests. . . . [Shot inside control room with electronic and monitoring equipment] . . . there is much to be checked. Telemetric controls monitor 2,000 parameters in this system. . . . Our cameras are now 12 kilometers from the launch pad, which is perhaps a safety zone 10 times further away than when a rocket with cosmonauts is launched. But that time again, the engines . . . are more than 10 times more powerful. [Shot of tulips and horses in the steppe] . . . the power of the rocket that is to go into space today is 170,000,000 h.p. [Shot of vehicle on launch pad] Its launch weight is more than 2,000 tonnes. It is 60 meters high . . . There are four engines in the central unit and one engine of each of the side units, which are also four in number. These . . . are the most powerful in the world today. . . . [Shot of control room showing launcher on monitor] New materials have been developed in its construction, along with new technologies and production units.
>
> You can see on the monitors various sections of pipeline and tanks. This is the moment of filling the rocket with fuels. The fuel is being fed from a cryogenic center. First, tanks in the central unit are filled with nitrogen forcing the air out, then with hydrogen gas forcing the nitrogen out—this goes on for hours as if rinsing. [Shot of launch pad] Liquid oxygen is going to tanks along another circuit; they will meet only in the combustion chamber for detonation. [Shot of Tikhomirov with microphone in front of monitor showing launcher] The new launcher is shrouded in hoar-frost. . . . Remote-control cameras positioned near the launch pad are working now, while (the cameras of Central Television) can now, at night, only make out the launch pad as a spot of light in the distance.

Throughout this TV report the resemblance between the DOD's drawing of the heavy-lift launch vehicle[79] and the actual rocket with its side-mounted payload was most striking. The dummy payload appeared slightly smaller in diameter and rather longer, terminating in a sharp rather than a rounded nose-cone and the strap-ons had box-like features at top and bottom which caused Western analysts to speculate that they housed recovery parachutes. The dummy payload was painted black and the overall color of the launch vehicle was gray.

By measuring the time between lift-off and clearing its own height it was possible to calculate an initial upward acceleration of approximately 0.7g, implying a maximum force of 1.7g acting on the payload at launch.

This was the first time that liquid hydrogen engines had been used in the Soviet space program and all eight engines were burning at lift-off.

More details emerged from a TASS interview with Guriy Marchuk, the President of the Soviet Academy of Sciences, during the following week.[80] He described Energiya as a two-stage rocket of "package" design, with a strap-on payload. The first stage consists of four strap-on booster engines using kerosene and liquid oxygen, while the second stage is the central core, eight meters in diameter, burning liquid hydrogen and liquid oxygen. As a multi-purpose system it was able to place into LEO either reusable spaceships (such as the U.S. space shuttle orbiter) or other large-sized space vehicles. It was the basic unit of a reusable space transport system being created in the Soviet Union. It could be used to put heavy communications satellites into GEO, launch interplanetary stations into deep space and towards the Sun, for the assembly of versatile orbital complexes consisting of large-size modules and structural elements, and putting experimental solar power plants in orbit with a wide spread of solar cell batteries for use in space production, potentially opening up near-Earth space to industrialization.

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[78] Soviet television, 1700 GMT, May 16, 1987.
[79] Soviet Military Power 1986, op. cit., p. 49.
[80] TASS, 1733 GMT, May 21, 1987.

In an interview for *Izvestiya,*[81] Academician Avduyevskiy claimed that Energiya had fully accomplished the task assigned to it, both stages being tested in real flight conditions. Although the mock-up satellite orientation system failed regarding the operation of the engine which should have placed it into a higher orbit, this regrettable set-back had no bearing on the Energiya rocket in his opinion.

Aleksandr Dunayev, head of Glavkosmos, was more specific in an interview released at the beginning of June.[82] He stated that the payload, of more than 100 tonnes, could be either a satellite, module of an orbital station or a space shuttle. The aggregate thrust of all engines is 4,000 tonnes and it had the capability of launching spacecraft weighing more than 30 tonnes to the Moon and probes of approximately the same weight to Venus or Mars. He said that, with its aid, a large permanent mobile laboratory could be landed on Mars and that it brought closer to reality the establishment of large extra-terrestrial production units and scientific laboratories, not only in LEO. In an extract released later,[83] he stated that, when it was fully developed, Energiya could be supplied on a commercial basis to foreign partners. Writing in *Pravda,* Dunayev mentioned that the maximum cross-sectional dimension is 20 meters.[84]

More precise data are given in an earlier interview by Cosmonaut Sevastyanov with Professor Sergey Grishin, deputy Flight Control chief.[85] Payload capability to the Moon was said to be 32 tonnes, and 27 tonnes to Venus or Mars.

An article on the launch control systems for Energiya draws attention to an innovation in the rocket's structure—cryogenic hardening of the metal used for tanks and compressed gas cylinders and their interconnecting units to increase strength and reduce weight by use of thinner metal walls.[86]

Such a spate of information provided Western analysts with an opportunity for speculation and articles were soon forthcoming. One speculated that the payload fell in the Pacific Ocean several hundreds of kilometers to the north-east of Hawaii.[87] Anthony Lawton speculated that versions with 4, 6 or 8 first-stage strap-on recoverable boosters of the SL–16 type could exist and decided that plug nozzles rather than conventional bell-mouthed venturi nozzles were employed. He surmised that the payload engine would have employed nitrogen tetroxide (N2O4) and unsymmetrical dimethylhydrazine (UDMH). He also provided detailed drawings of how the first stage boosters might be recovered by parachute, using retrorockets to reduce impact velocity on landing with the axis vertical and sacrificing tankage, which would be crushed on impact in order to be able to reuse the engines.[88]

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[81] TASS, 1827 GMT, May 22, 1987.
[82] TASS, 1232 GMT, June 1, 1987.
[83] TASS, 1558 GMT, June 1, 1987.
[84] Dunayev, A. Pravda, June 11, 1987, p. 6.
[85] Soviet television, 2150 GMT, May 29, 1987.
[86] Karashtin, V., Izvestiya, June 12, 1987, p. 3.
[87] Christy, R. Space Flight News, no. 19, July 1987, p. 38.

A newspaper article came up with similar concepts but with the first-stage boosters landing horizontally on skids after a radio- controlled landing on parawings and horizontal recovery of the second-stage core with impact cushioned by an air-bag.[89] It reported that studies by Commercial Space Technologies indicated that, even on its first flight, Energiya matched the U.S. shuttle launch price of $3,250 per pound weight and that, after 20 years use, Energiya's launch costs could be as low as $200 per pound. The *Spaceflight* and *Times* articles had drawings showing an up-rated version of Energiya with eight first- stage strap-ons and a third stage on top of the second-stage core as did articles appearing around the same time in *Flight International.*[90] These all appear to have derived inspiration from early DOD speculative drawings.[91] [92]

A more numerical analysis by Phillip Clark gives estimated dimensions of the strap-ons as around four meters in diameter and 39 meters in total length, of which 34.5 meters is cylindrical. These dimensions suggest a dry mass of around 42 tonnes and a propellant mass of around 385 tonnes.[93] The excrescences at top and bottom of each strap-on are referred to as panniers which may be part of a recovery system, consisting of a parachute container and stabilizing fins for the descent to Earth. The scaled length of the second-stage, based on the announced eight meter diameter, is close to 57.5 meters, implying a dry mass of around 55 tonnes with a propellant load of around 800 tonnes. It is pointed out that the core ignites 12.3 seconds before the strap-ons. Clark's measurements confirm the 1.7g force at launch stated above and he reaches the conclusion that this first launch of Energiya involved a vehicle loaded with only 77 percent propellant.

Information, which would be of interest but has not yet been published, is the inclination of the intended orbit for the dummy payload, or the locations of the impact points in the Pacific Ocean, from which that inclination could be readily calculated. Some Western analysts have assumed that the inclination would have been close to the 51.6° currently used for piloted spaceflight and the initial orbits of the majority of the Proton launches. However, it is a fact that the inclinations used for the initial flights of the A, C, D and J-vehicles have all been close to 65°.

Models of Energiya were not ready for the 1987 Paris Air Show, but one was displayed, bearing the Glavkosmos logo, in Moscow at the Space Future Forum to celebrate the 30th anniversary of the launch of the first Sputnik during the first week of October.[94] It was also displayed on the Soviet stand in the exhibition at the 38th Congress of the International Astronautical Federation (IAF) in

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[88] Lawton, A. T. Spaceflight, August 1987, pp. 285–289.

[89] The Times, London, August 11, 1987.

[90] Flight International, September 19, 1987, p. 51, and September 26, 1987, p. 31.

[91] Soviet Military Power 1983, op. cit., p. 68.

[92] Soviet Military Power 1984, op. cit., p. 44.

[93] Clark, P. S. Space, September–October 1987, pp. 36–39.

[94] Aviation Week and Space Technology, October 12, 1987, p. 24.

Brighton, England, shortly afterwards. The model revealed that the dummy payload had a single nozzle at the base of the cylinder with two smaller cylinders, which might also be thrusters, on opposite sides at the lower end of the main cylinder. There is a small increase in diameter of the cylinder, approximately one quarter of the way down from the base of the nose-cone. The strap-ons are seen to have four nozzles each. The tip of the central core terminates in a nipple-like feature, just as depicted in the DOD's artist's impression of the Soviet space shuttle on the launch pad.[95]

The questions of total or partial recovery of the first and second stages persisted right through to October. Soviet program officials speaking to U.S. delegates to the Space Future Forum during the first week of October described Energiya as a recoverable vehicle. Leonid Kasperovich of Moscow's Space Research Institute (IKI) said that Energiya is designed to be separated into seven sections which return to Earth by parachute after burning its fuel. The four booster rockets descend separately and the main section breaks into three portions. All the elements could be reused according to this account.[96] It was also said that although the strap-ons and portions of the core were designed to be recovered, the system was not fully exercised on the first flight and no elements were recovered.[97] The report said the large liquid strap-on boosters were designed to be recovered with parachute braking systems, contained in external packs on the forward and aft ends of each booster section, which would orient the booster in a horizontal attitude for the descent. The same report revealed that the second Energiya was being prepared for launch in the coming months, but said that program officials wanted to ensure that anomalies that occurred on the first flight were fully understood and resolved before another launch was made. Lift-off of the first flight was planned for daylight hours, but was delayed by last-minute technical problems.

Soviet delegates to the IAF Congress two weeks later, however, caused confusion with varying statements about total or partial reusability. Soviet officials, including one of Energiya's designers, insisted at the Current Events Session that there had been many design options, but the existing system is not reusable.

### COMMERCIALIZATION OF SOVIET LAUNCH VEHICLES

One of the important tasks of Glavkosmos [98] is marketing space hardware on a commercial basis. One of the main directions of these services is the launching of foreign satellites by Soviet launch vehicles.

In 1983 the Soviets had proposed that second-generation maritime communications satellites for the International Maritime Satellite Organization (Inmarsat), of which the Soviet Union was a founding member and is a major shareholder, be launched by Proton,[99] but no contracts were forthcoming.

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[95] Soviet Military Power 1986, op. cit., p. 58.

[96] AP News, October 5, 1987.

[97] Aviation Week and Space Technology, October 15, 1987, pp. 22-24.

[98] See volume 2 of this report.

[99] Aviation Week and Space Technology, June 20, 1983, p. 18.

One of the first Western organizations to show an interest was the Space Commerce Corporation of Houston, Texas. This is a privately-held corporation devoted to selling Proton services for U.S. manufactured communications satellites. With the grounding of the U.S. space shuttle in January 1986 and suspension of launches by Arianespace following the loss of the first Ariane 2 in May, Western satellite owners began to look seriously at the Soviet initiative.

In July 1986, a spokesman for Glavkosmos said that using a Proton rocket to launch a satellite would cost any country 50 percent less than if a rocket of the European Space Agency's Ariane-type were used.[100] This estimate was revised in the following month to "20 percent less than what is charged for putting a spacecraft in orbit by the Ariane rocket." [101]

The 20 percent less than the European Space Agency's estimate was repeated by Poletayev, department head of the Soviet State Committee for Space in an interview for Moscow News, with specific reference to the use of the "Proton" to launch a satellite for Inmarsat.[102] Poletayev went on to claim that the real reason for the American embargo on technology transfer (see below) was the desire to monopolize the market at any price and in all circumstances.

The U.S. Government, fearing possible technology transfer, had raised objections and invoked restrictions preventing most Western satellites from being launched on Soviet launch vehicles. At the 1986 IAF Congress in Innsbruck, Aleksandr I. Dunayev, Glavkosmos chairman, called for an end to such restrictions and said that Western spacecraft booked for commercial missions on Proton or other vehicles launched from the Soviet Union could be surveyed continuously by the customer to ensure that there was no unauthorized technology transfer.[103] He said that, if the contract specified that a visiting team could accompany the satellite, then that team would be allowed onto the launch site. However, he acknowledged that their launch sites did not have, at that time, the infrastructure to support large- scale commercial operations, but claimed that the necessary facilities could be built in response to customer demand.[104]

Dunayev reiterated Poletayev's claim about the U.S. embargo blocking international cooperation in space in a full-page interview for the Economic Gazette.[105]

While in Geneva to deliver a lecture at the International Research Institute, Dunayev met representatives of 20 firms and companies from leading Western countries, including the United States, Great Britain, France, the Federal Republic of Germany and Italy, and gave the approximate costs and conditions of providing the services of Soviet space technology commercially for launching satellites.[106]

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[100] Radio Moscow World Service, 1500 GMT, July 28, 1986.
[101] Radio Moscow World Service, 1000 GMT, August 27, 1986.
[102] Moscow News, September 1986, p. 10.
[103] Aviation Week and Space Technology, October 20, 1986, p. 104.
[104] Ibid.
[105] Ekonomicheskaya Gazeta, March 1987, p. 20.
[106] TASS, 1517 GMT, May 22, 1987.

At a press conference he noted that the chief obstacle to the development of cooperation remained the U.S. ban on exporting technology to the socialist countries since Western space equipment usually contained American components. He said that the removal of the barrier would open the doors to broad development of mutually advantageous and useful contacts and to the expanded access for other countries to the peaceful conquest of space.[107]

A Glavkosmos/Licensintorg briefing was held in Washington, D.C., on May 14, 1987, under the auspices of the Commercial Space Group of the law firm Heron, Burchette, Ruckert and Rothwell, which specializes in Soviet trade.

The British insurance brokers, Jardines, at a meeting for representatives of industry and the media[108] announced that Jardine Glanvill (Interplanetary) Ltd. had entered into a consultancy agreement in September 1987 with Licensintorg to market Soviet launch vehicles to commercial communications companies in Europe and newly industrialized countries. The partnership had developed from initial discussions on insurance.

On each of these occasions, seven different launch vehicles were on offer. Table 32 presents the specifications for technical performance using the exact wording of a document included in the press kit for the meeting.

TABLE 32.—LAUNCH VEHICLES OFFERED BY GLAVKOSMOS

| Name | Number of stages | Bipropellant | | Capability |
|---|---|---|---|---|
| | | Oxidizer | Fuel | |
| Cosmos | 2 | Nitrogen oxide | Carbon hydrozine | Payload mass of 450 km (sic) at altitude of 500 km[1]. |
| Tsyklon (Cyclone) | 3 | Nitrogen tetroxide | Unsymmetrical dimethyl-hydrazine. | Payload mass of 4,000 kg at altitude of 200 km. |
| Vertical | | | | Geophysical (exploration) rocket being designed for the investigation of upper atmosphere and in the field of astrophysics; Retrievable instrument package mass of 860 kg (scientific apparatus mass —560 kg) to altitude of 1,500 km. |
| Soyuz | 3 | Liquid oxygen | Carbon hydrozine (kerosene). | Payload mass of 7,000 kg at altitude of 200 km. |
| Vostok | 3 | Liquid oxygen | Carbon hydrozine (kerosene). | Payload mass of 4,730 kg at altitude of 200 km. Payload mass of 1,840 kg into sun-synchronous orbit at altitude of 650 km. |
| Molniya | 4 | Liquid oxygen | Kerosene | Payload mass of 1,500 kg into high elliptic orbit at altitude of 36,000 km. |
| Proton | 3,4 | Nitrogen | Dimethyl-hydrazine | Payload mass of 21 t[2] into circular low Earth orbit; 2.2 t GEO at any fixed point; departure orbits Moonward—5.7 t, Venusward—5.3 t, Marsward—4.6 t. |

[1] Presumably intended to be 450 kg, or 0.45 t. This is only one-quarter of the DOD estimate given in table 28.

[2] 1,000 kg=1 t (metric tonne) All vehicles offered for commercial use having been operational for a long time and have good launch statistics.

Prepared for the Congressional Research Service by G.E. Perry.

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[107] Ibid.

[108] Hadlington, S. Nature, November 12, 1987, p. 98.

The document laid down the general conditions on marketing of the Soviet launch-vehicle services for the foreign customers as follows:

1. Transportation of the spacecraft and necessary test equipment is performed by customers in two ways:

   (a) by the "Aeroflot" charter flight from the manufacturer directly to the Baikonur airport and then by special motor transport to the launching site.

   (b) delivery of the satellite by the customer's means of transport to Moscow, then by "Aeroflot" plane to the Baikonur launching site.

In both versions the satellite and test equipment are free from customs examination and duty.

2. Spacecraft and special equipment would be accompanied by the customer's staff.

During transportation the right to participate at all stages of activities on a 24-hour basis would be guaranteed for specialists accompanying the satellite and test equipment.

3. Insurance.

The question of satellite insurance would be decided under a private contract between the customer and the Soviet joint-stock company "Ingosstrach." It is noted that the Soviet insurance rates will be lower than that of the world market.

In an interview following the launch of Energiya, Dunayev stated that, when it was fully developed, it also could be supplied on a commercial basis to foreign partners.[109] In light of this it is pertinent to note that the only Soviet launch vehicle not being offered for commercialization is the J-vehicle.

Boris Pyadyshev, first deputy head of the Soviet foreign ministry information directorate, also commented on the American embargo at a briefing for Soviet and foreign journalists. He said that the Soviets were prepared to guarantee that customers' interests would not suffer either in terms of money or from the viewpoint of the preservation of technological or other secrets. The U.S. companies General Motors and General Electric were reported to have shown interest in the Soviet proposal.[110]

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[109] TASS, 1558 GMT, June 1, 1987.

[110] Novosti Press Agency, op. cit., p. 9.

# CHAPTER 4—SUPPORT SERVICES

## Ground-Based Support

### THE KALININGRAD SPACE FLIGHT CONTROL CENTER (TSUP)

The work of the Flight Control Center (FCC) was described in an article by A. Militsin, FCC chief.[1] The ballistics data computing system operates first to compute an accurate launch time and desired parameters for orbit-injection. Estimated data on the actual orbit is received several minutes after the launch and in 10 to 15 minute predictions for the ballistic lifetime of the spacecraft and proposals for orbit corrections are produced. The coordinates of emergency landing areas are determined. During the flight the ballistics data computing complex provides the input data necessary for organizing all flight control operations, calculating the time and duration of engine firings, the orientations needed to perform the different flight tasks, and how the command, control and communications stations should track the spacecraft.

The greatest volume of data received comes from telemetry. Eight-hundred thousand units of information were received daily from the Salyut 6-Soyuz complex and processed by the data computing complex. This was said to be equivalent to "the complete text of an edition of Aviatsiya i Kosmonavtika every second." [2] Data output from 150 channels is sent to 500 monitor consoles where specialists can retrieve the desired information on a display screen by pressing a maximum of two keys. On-line command communications consoles provide both individual and collective communications for the specialists. It was said that space flight chiefs, the communications chief and duty shift chiefs have direct communication with the crew and that their working places were also equipped with television camera transmitters. As a rule the chief operators are cosmonauts training for subsequent flights.

Balayan's technical memorandum, cited previously, gives a detailed account of the FCC, organization of work in the control room, control room operational support, and the training of control personnel.[3]

An illustrated booklet giving a general description of the Kaliningrad Spaceflight Center near Moscow, where orbiting and interplanetary spacecraft are monitored and controlled, was published in 1985.[4] As well as engaging in the actual flight control of spacecraft, the staff also carry out scientific investigations and develop methods and algorithms for solving flight control problems.

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[1] Aviatsiya i Kosmonavtika, December 1981, pp. 40–41.

[2] Ibid.

[3] U.S. Office of Technology Assessment. op. cit., pp. 57–59.

[4] Tsentr Upravleniya Poletom, Mashinostroyeniye, Moscow, 1985.

The FCC monitors the work and condition of the crew of piloted spacecraft via onboard and ground equipment, programming their operation. Programs are developed by gathering, processing and analyzing information about the condition of all elements of spacecraft and ground equipment. Telemetry transmitters (about 1,000 on the spacecraft and more than 2,000 in the Center) produce readings 100 times a second.

In the control process, the FCC performs operational guidance of the flight and coordinates the operation of a network of ground-based tracking stations, the space support fleet of the Soviet Academy of Sciences, and ballistic centers. It interacts with the launching and recovery complexes, training-simulation facilities, and various other flight support organizations.

It reports both the date and the exact time of launch to the cosmodrome and, until the spacecraft is injected into orbit, receives telemetry information from the cosmodrome about the condition of the spacecraft's onboard systems and the health of the cosmonauts, television pictures from the launch site and the onboard TV cameras, communications between the cosmonauts and launch control, data on the progress of pre-launch preparations and the launch itself when it occurs.

During the flight, the FCC maintains communication with remote ground and floating stations with the aid of communication satellites. It specifies raw data for tracking stations to compute look-angles in azimuth and elevation when the spacecraft is above their radio horizons. Ballistics determine the orbital parameters of the spacecraft on the basis of radio measurements received from the tracking stations. Several hundred communication channels guarantee effective interaction of control groups simultaneously on several subjects.

A common timing system synchronizes operation of the FCC's computers. High precision of time-keeping (Moscow Standard Time, Greenwich Mean Time, Universal Coordinated Time, etc.) is guaranteed by a permanent link to the State Standard Time for radio and television channels.

A complex of tele-optical projection equipment, an alpha-numeric display controlled automatically by a system with an output of 1.5 million operations per second, guarantees the versatility and clarity of the large screen displays of generalized information about the flight path.

The performance of the spacecraft's onboard systems is evaluated by real-time processing some 3,000 telemetry parameters displayed in various forms for the controllers. During a communication session, information is received at a rate of approximately 500 kilobytes per second. Telemetry data processing, ballistic and command-program calculations are made using "El'brus" multiprocessing computer systems with 2,000 megabytes of internal and external storage.

Visual display units provide the data necessary for the controllers during operation. These include the results of ballistic- navigation calculations, telemetry data on the operating conditions of onboard systems and scientific equipment, and various types of reference information. The communication system makes it possible to carry on coversations both with the individual specialists and a group of subscribers. Individual specialist workstations are provided with equipment for space-video communication.

At the close of each communication session, the FCC's specialists remain at their consoles until the results of the session are analyzed and all reports have been received by the shift Flight Director.

Television shots from within the FCC appear from time to time, such as at the launch of the two Vega spacecraft and the launch of a crew with a foreign cosmonaut. During the summer of 1987, a team from the BBC's Children's TV program, "Blue Peter," who were making a series of features about the Soviet Union, were permitted to visit the Kaliningrad FCC. Presenter Yvette Fielding and BBC veteran space correspondent Reg Turnill were shown around the Center by Cosmonaut Vladimir Solovyev, Deputy Flight Director for the Soyuz TM-2/TM-3 mission. During their five-hour visit they received a special message to the young viewers of their program from Cosmonauts Romanenko and Aleksandrov onboard the Mir orbital station.[5] Turnill said that there appeared to be a team of 25 in the shift, approximately equal numbers of either sex and that, for much of the time, two or three consoles only were occupied between communications sessions.[6]

With the appearance of the Mir orbital station, Kettering Group members who were monitoring the voice communications between the cosmonauts and the ground noticed a departure from the long-established calling-up routine. In piloted missions to the Salyut stations, the cosmonauts would usually begin a communication session by calling "Zaria" (Dawn), the call sign of the control center. Romanenko and Laveikin, on Mir in 1987, used the new call-sign, which sounded like "Soup," heard occasionally in 1986 from Kizim and Solovyev. This is, in fact, the pronunciation of the initial letters "TsUP" for "Tsentr Upravleniya Poletom" or FCC.

### THE GROUND AUTOMATED CONTROL COMPLEX (NAKU FORMERLY THE KIK)

The "Nazemniy Avtomatizirovanniy Kompleks Upravleniya" (NAKU) is the basic complex, universal to all types of spacecraft, of permanent and mobile systems and resources for exchanging command, telemetric and trajectory information with spacecraft, and resources for communication and automated collection and processing of information, together with necessary software, and intended to control all spacecraft functioning in space.[7]

A rudimentary command-measurement complex (KIK) encompassing the entire territory of the Soviet Union had been established in the 6 months prior to the launch of the first sputnik in 1957. Due to the relative simplicity of the early sputniks, the initial tasks of the KIK were comparatively simple. In the second phase, the KIK began to provide backup for the operation of space objects in orbital flight. The 1983 KIK was "a complicated, multifunctional, technically unique, automated control complex for controlling all of the Soviet space apparatuses, vehicles and stations in active existence in space."[8] Tamkovich disclosed that occasionally, in order to ensure uninterrupted communications with spacecraft on especially important parts of the flight, if it could not be done by ground stations or if it were impossible or inexpedient to use ships, aircraft were used.[9] Elsewhere he wrote that the main task of the KIK, during the first revolution of a piloted spacecraft, "was the monitoring of the lift-off into orbit, deployment of antennas and solar battery panels, as well as checking on the state of the cosmonauts' physical well-being and functioning of onboard systems, while on the second revolution they begin testing the spacecraft orientation systems and preparations for the first maneuver."[10]

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[5] The program was transmitted on BBC1 TV, 1605 GMT, October 19, 1987.

[6] Private telephone call to G. E. Perry, 1742 GMT, October 23, 1987.

[7] Kosmonavtika Entsiklopediya, op. cit., pp. 260–262.

The 1985 encyclopedia reproduces an organizational chart. A central command post (TsKP) has two-way interaction with the ballistic centers (BTs) and the telemetric processing center, which have a two- way link with the communication and data transmission subsystem, and the central spacecraft control point (TsPU) for automated spacecraft or the FCC (TsUP) for piloted spacecraft. Two-way links between the communication and data transmission subsystem provide control of ground resources from the TsKP and spacecraft control from the TsPU or TsUP. Control is linked from the communication and data transmission sub-system to the ground-based (KIP, formerly NIP) and ship command and measuring stations (KKIP) and measurements are returned to the communication and data transmission sub-system from the KIPs and KIPPs, and from airborne measuring stations. There is a telemetry link from the spacecraft to the airborne measuring stations and two- way telemetry, radio orbit control, command information and communication links between the spacecraft and the KIPs and KKIPs.[11]

## Sea-Based Support

A TASS announcement describing a book giving a detailed description of the ships of the Soviet Academy of Sciences, published in 1980,[12] claimed that the flotilla had more than 10 vessels operating in various parts of the world ocean. The need for them was explained by the fact that space vehicles are within direct visibility from ground stations on Soviet territory for about 9 hours only out of 24.[13]

Additional details, taken from the 1980 book, follow.

### STRUCTURAL DESIGN CONSIDERATIONS

The architectural appearance of the ships is determined primarily by their antenna systems. The 25m dish reflector on the Kosmonavt Yuri Gagarin or the 18m white spheres of the radomes on the Kosmonavt Vladimir Komarov attract attention to themselves immediately, creating a lasting impression of the ship. A closer inspection reveals many other antennas of differing designs and sizes. No ship of any other class has such an abundance of antennas.

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[8] Tamkovich, G. M. Zemlya i Vselennaya, March-April 1983, pp. 46–52.

[9] Ibid.

[10] Tamkovich, G. Aviatsiya i Kosmonavtika, June 1983, pp. 44–45.

[11] Kosmonavtika Entsiklopediya, op. cit., p. 261.

[12] Bezborodov, V., and A. Zhakov. Suda kosmicheskoy sluzhby. Sudostroyeniye, Leningrad, 1980.

[13] TASS, 1015 GMT, November 20, 1980.

The antennas and radio apparatus with which the expedition laboratories are equipped impose conditions which are specific for ships of this class. The scientific assignments of expedition voyages dictate the requirements for the sea-going qualities of the ships.

Good sea-going qualities are necessary in order that the scientific tasks can be fulfilled while sailing in any part of the world oceans at any time of year and in any weather. Stations are determined by satellite trajectories without regard for the weather. A ship may not be able to choose its course to minimize the effects of waves since the course will be determined by communications sessions, the heading of the spacecraft's trajectory and the viewing angles of the ship's antennas. It must also be able to be controlled well at low speeds and while drifting—typical conditions, if not at anchor, when conducting communications sessions with spacecraft. A ship's stability and rolling characteristics are critical design factors. The radio engineering and electronic equipment, which are the basis of such vessels' equipment, have weight distributions which are disadvantageous to stability. The antenna systems, the heaviest elements, are located high above decks and superstructure, whereas the lighter electronic equipment is below decks. This raises the ship's center of mass toward the metacenter [14] to a considerable degree. Stability difficulties also arise from the large surface areas of the antenna dishes and radomes, particularly when the wind is from abeam. Communication sessions therefore are not held in high winds and antennas are locked, pointed vertically in the "travel" position when the ships are under way.

Rolling, due to wave-action, creates considerable interference for space communication sessions. Heavy rolling leads to an increase in the loads on the antenna stabilization system and lowers their aiming accuracy. A secondary effect is on the fitness for work of the ship's personnel. Reduction of rolling is therefore a major consideration in design and various types of stabilizer are employed.

Hull-strength reinforcement is necessary at points where massive antennas and other heavy pieces of equipment are installed and multiple highly-directional antennas on the same ship call for increased hull-rigidity. Ships' hulls are reinforced to withstand ice when sailing in sub-polar latitudes or in middle latitudes during the winter months.

## SELF-SUFFICIENCY

Space service ships must be highly independent—able to remain at sea for long periods, performing their mission, without having to put into port to replenish stocks of fuel, fresh water and provisions. A high degree of independence permits uninterrupted communication sessions and avoids wastage of time during passage from the working location to port. By the very nature of their missions, working locations are usually remote from port, particularly Soviet home ports, and the significant loss of operational time that would be occasioned without a high degree of independence could necessitate an increase in the number of vessels needed to maintain the necessary support coverage.

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[14] The point through which the resultant buoyancy force always acts. The equilibrium of a floating body is stable so long as the center of mass lies below the metacenter.

Independent sailing is limited by the stocks of fresh water and provisions. Ships are equipped with large refrigerated storerooms for provisions and independence is increased through use of distillation units for water supply. Ships of the Belyayev class can sail for 90 days without replenishing their provisions and carry a 30-day fresh water supply. The Kosmonavt Yuri Gagarin can sail independently for 130 days. Replenishment of its fresh water supply is necessary after 60 days. Its two distillation units produce 40,000 litres (10,567 U.S. gallons) of water per day. The drinking water is chemically treated to make the composition and taste quality as good as that of Moscow's water supply.

## PARTICULAR CHARACTERISTICS

The first part of the appendix to this chapter comments on the various antennas and other details that can be seen in aerial photographs taken of the ships on their passages through the English Channel. Numerical data provided in the book is presented in table 33.

TABLE 33.—COMPARATIVE DATA FOR SOVIET SPACE SUPPORT FLEET

| | Kosmonavt Yuri Gagarin | Kosmonavt Vladimir Komarov | Akademik Sergey Korolev | Kosmonavt Vladislav Volkov | Kegostrov |
|---|---|---|---|---|---|
| Length (m) | 231.6 | 155.7 | 180.8 | 121.9 | 121.9 |
| Beam (m) | 31.0 | 23.3 | 25.0 | 16.7 | 16.7 |
| Midship side height (m) | 15.4 | 14.8 | 18.2 | 10.8 | n/a |
| Displacement (tonnes) | 45,000 | 17,850 | 21,250 | 8,950 | 6,100 |
| Draft (m) | 8.5 | 8.8 | 7.7 | 6.6 | 4.7 |
| Engine power (h.p.) | 19,000 steam | 9,000 diesel | 12,000 diesel | 5,200 diesel | 5,200 diesel |
| Cruising speed (knots) | 18.0 | 15.8 | 17.5 | 14.7 | 15.6 |
| Range (miles) | 20,000 | 18,000 | 22,500 | 16,000 | 16,000 |
| Crew | 136 | 121 | 119 | 66 | 53 |
| Scientists and engineers | 212 | 118 | 188 | 77 | 36 |
| Provisions (tonnes) | 180 | 85 | 105 | n/a | n/a |
| Water (1000 litres) | 2,100 | 320 | 810 | n/a | n/a |
| Date of maiden voyage | 7/16/71 | | | 10/18/77<br>[1] 3/15/78<br>[2] 10/14/78<br>[3] 10/19/78 | |

[1] Kosmonavt Pavel Belyayev.
[2] Kosmonavt Georgiy Dobrovolskiy.
[3] Kosmonavt Viktor Patsayev.

Notes.—A variety of unitary systems has been used. Conversion factors are as follows: 1 metric tonne = 2204.6 U.S. pounds; 1 litre = 0.264 U.S. gallon; 1 kilometer = 0.621 mile; 1 nautical mile = 1.152 mile; 1 knot = 1 nautical mile per hr = 1.855 km.p.hr.

Prepared for the Congressional Research Service by G.E. Perry.

The Morzhovets, Borovichi and Nevel are described as having the same characteristics as the Kegostrov.

The book also goes into great detail about crew amenities—one and two bed cabins, both with showers, suites for the ship's command staff and the expedition leader, some with conference rooms attached, recreation rooms, a library with reading room, a 250-seat cinema, a gymnasium with swimming pool in addition to two open pools on deck, wardrooms and messes, and a medical unit comprising an operating theatre, sick bay, dispensary, X-ray room, and physical therapy and dental offices are listed for the Kosmonavt Yuri Gagarin.

### GENERAL LOCATIONS OF THE SPACE SUPPORT FLEET

An analysis of the locations of Soviet tracking ships during piloted missions was published in 1973.[15] It showed that during most of the Soyuz flights up to that time, one of the three larger vessels was anchored off Sable Island, Nova Scotia (about 44.5°N, 59.5°W) where four successive orbits, which do not cross the territory of the Soviet Union, pass within easy direct communication range. The location is still in use today. On revolutions with ascending nodes between 100°W and 140°W, it is possible for observers in the United Kingdom to listen to the cosmonauts' voice transmissions through the Sable Island ship for one or two minutes as Mir rises above their horizon. There then follows a break in communication of some three to four minutes as the orbital station passes beyond the radio horizon of the ship until it reaches the zone of communication with a Soviet ground station or another ship stationed near Gibraltar. The cosmonauts are still in contact with the FCC as their orbital station passes out of the area of reception of transmissions for U.K. monitoring stations.

Another location connected with piloted flights is in the Gulf of Guinea, West Africa, to monitor retrofire prior to re-entry and landing in Kazakhstan, U.S.S.R. The first ignition of the Proton booster's fourth stage, used to take deep space flight probes, geosynchronous and semi-synchronous payloads out of LEO occurs at the first ascending node, which is situated over the equator close to 10°W, and can be monitored from this location. When a deep space flight occurs and probes lose velocity as they climb away from the Earth, the ground-track makes a U-turn over the South Atlantic and heads westward over Central America. Hence, there are often tracking ships deployed along this South Atlantic track which otherwise would be difficult to observe from Soviet territory. A large support ship in a Cuban port or stationed in the Caribbean provides additional coverage during the critical early phases of a deep space mission.

South Atlantic and Caribbean ships, together with vessels stationed in the Straits of Gibraltar and the Mediterranean, also fill in large gaps in communications between the orbital space stations, such as Salyut and Mir, and the FCC.

Another location east of the Philippines is occasionally seen in pictures showing the map of the world display in the FCC[16] and was once depicted on the 32 kopek stamp issued to commemorate the Soyuz 30 mission in 1978. None of the ships of the Academy of Sciences has ever been identified in such a location and the implication is that the vessel is a naval missile tracking ship from the Pacific fleet. The world map display indicates the radio horizons of the seven tracking stations located on Soviet territory and of the three larger and four medium sized vessels of the space support fleet if their locations happen to lie in the vicinity of the projected ground tracks. The locations of the four smaller vessels are rarely incorporated in these displays.

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[15] Oberg, James. Soviet Tracking from the Sea. Flight International, November 15, 1973, pp. 828–829.

[16] Spaceflight, v. 22, 1980, p. 53; Time, October 5, 1987, p. 68.

A more detailed study, for the period covered by this report, is given in the second part of the appendix to this chapter.

### THE MARSHAL NEDELIN AND OTHER NAVAL MISSILE RANGE SHIPS

A new naval space and missile tracking ship made its appearance in 1984. The Marshal Nedelin was completed at the Admiralty Yard, Leningrad, in 1983 and made its maiden voyage directly from the Baltic to the port of Vladivostok, the headquarters of the Pacific Ocean Fleet. A sister ship is reported to be under construction.[17]

Its dimensions are given as 214 meters in length and 27.1 meters beam with a draft of 7.7 meters. Its displacement is quoted as 25,000 tonnes. Its twin gas turbine engines, each providing 27,000 h.p., give it a speed of 20 knots. The ship's complement totals 500 and it carries 2–4 helicopters.

It is fitted with a variety of space and missile associated electronic systems. For space associated communications it is equipped with one "Ship Globe" amidships. For space tracking there are three "Quad Wedge," one "End Tray" (balloons), one "Quad Leaf" and four smaller antennas. Three "Palm Frond" antennas are used for navigation and one "Fly Screen" antenna is devoted to helicopter control.[18] Photographs of the Marshal Nedelin have been published in Jane's Fighting Ships,[19] the DOD's "Soviet Military Power," which reported that it was currently operating in the West Pacific,[20] and, in color, in "The Soviet Space Challenge." [21]

A few details have emerged about the older and smaller naval missile range ships. The Sutchan has been re-named Spassk. Sakhalin and Sibir have three radomes fore and aft and all carry a flight deck and one helicopter. Chukotka is flush-decked, whereas the other three of the class have a forward well-deck. One ship, unspecified, has been refitted and now has a new funnel, mast and electronics.[22]

Chumikan was in the task force on both occasions for the recoveries of the small spaceplane from the Indian Ocean. On the first occasion the Kosmonavt Georgiy Dobrovolskiy was present [23] and on the second occasion the Kosmonavt Pavel Belyayev was on hand.

### SPACE-BASED SUPPORT

In 1981, the Soviet Union lodged details of a future Eastern Satellite Data Relay Network (ESDRN) with the International Frequency Registration Board (IFRB).[24] This three-satellite system would employ frequencies in the 10.8–15.1 GHz band (2 cm waveband) similar to those used by the U.S. Tracking and Data Relay Satellite System (TDRSS) and would commence operation "no sooner than December 1985." This information was presented diagrammatically in an earlier edition of this report.[25]

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[17] U.S. Dept. of Defense. Soviet Military Power 1985. Washington, U.S. Govt. Print. Off., April 1985, p. 59.

[18] Jane's Fighting Ships 1987–88. London, Jane's, 1987, p. 628.

[19] Ibid.

[20] Soviet Military Power 1986, op. cit., p. 139.

[21] The Soviet Space Challenge, op. cit., p. 8.

[22] Ibid.

[23] Aviation Week and Space Technology, June 14, 1982, p. 18.

[24] Special Section no. SPA-AA/343/1484 annexed to IFRB Circular no. 1484, September 1, 1981.

### THE LUCH SATELLITE: COSMOS 1700

The announcement, on October 26, 1985, of the launch of Cosmos 1700 included the phrase "experimental apparatus for relaying information by telegraph and telephone" and added that it operated in the centimeter waveband.[26] It took up station in geosynchronous orbit over 95°E, a location not used previously, but the central one of three locations registered with the IFRB for the ESDRN.

The first crew to the Mir orbital station in 1986 began their occupation on March 15, 1986. Two weeks later they tested a new radiotechnical system ensuring reliable communications between themselves and the FCC via "a relay transmitter, the Luch (Cosmos 1700) satellite" deployed in GEO. It was reported that the new system would make it possible to expand the possibilities of controlling the functioning of the sophisticated research complex and increase the volume and timeliness of outgoing information.

During a trial communications session via the Luch relay satellite, the cosmonauts presented a television report about the Mir station, which was shown later in the "Vremya" TV news program. Use of the name, Luch (Beam or Ray), could cause some confusion since it had already been used for the name of a transponder on a Gorizont satellite.[27]

The satellite was said to make it possible for the ground measuring complex to be visible and for Mir to be visible for a fairly long time. Communications sessions, which previously were from 15–20 minutes with Salyut 7, and with difficulty 30 minutes, had been considerably expanded. The crew at the FCC has an opportunity to observe the station both by the radio mode and the television mode for a considerably longer time—for about 40 minutes.[28] Testing was reported again nine days later.[29]

Ivakhnov provided further details in an article which claimed that the volume of information transmission between Mir and the FCC was 10 times that from Salyut 7—due to the onboard computers. Tracking stations had to be re-outfitted before Mir was launched to cope with the increased flow.

After an explanation of how, from the position of Cosmos 1700 in geosynchronous orbit above the equator, approximately due south of Baikonur, it is possible to see nearly one-half of the globe, he went on to write that Mir had a narrow-beam antenna connected to a computer. When the location of the communications satellite was given to the computer, it issued the necessary commands to the control systems. From this moment on, the narrow-beam antenna would turn so that it was always "looking" at the satellite. In the same way Cosmos 1700 would be looking with its antennas at Mir. It would transmit all incoming information to a tracking station located near Moscow, on the outskirts of the FCC.

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[25] Soviet Space Programs: 1976–80, Pt. 3. Washington, U.S. Govt. Print. Off., 1985, p. 780.

[26] TASS, 1216 GMT, October 26, 1985.

[27] Chausov, L. Pravda, May 7, 1984. p. 4. One of the satellites being used in the Dubna-Intercosmos space communications test program is the Luch-1, which is in geostationary orbit over the Atlantic Ocean.

[28] Radio Moscow Home Service, 1430 GMT, March 29, 1986. [Incorporating the previous extract]

[29] Izvestiya, March 30, 1986, p. 1.

The first such period of communications was said to have taken place on March 29 when the television link between Earth, the communications satellite and Mir operated without trouble.[30]

The crew gave a press conference during two communications sessions, including a lengthy one with the use of the Luch relay satellite, on April 27 and were said to have assessed highly the possibilities of the new teleradio complex.[31] [32]

During the communications session on April 27, one of the cosmonauts said that "problems and failures also crop up. For instance, we had a major problem with the communications system, we could not adjust it for a long time, but now, as you see, we are talking without major interruptions, so this problem has been solved." [33]

The Kettering Group had suspected that the cosmonauts were experiencing some difficulty in obtaining reliable communications through the Luch satellite. Transmissions monitored between March 20 and April 14 frequently contained repetitions of "raz, dva, tri .. tri, dva, adin" (1, 2, 3 .. 3, 2, 1) as the crew struggled to maintain the correct attitude for antenna alignment. On July 1, shortly after their return to Mir from Salyut 7, one of the cosmonauts could be heard in the background going through the lining-up routine while the other cosmonaut was talking to the FCC over the normal downlink. Such routines were monitored until July 9, one week before the cosmonauts' return to Earth.

Additional information was provided by Belgium's Theo Pirard following the Moscow Space Future Forum. Use of Luch was described as being "more difficult than expected." Precise alignment of the Mir station was time-consuming and expensive in terms of propellant consumption.[34] In reply to another guest's inquiry as to why Luch was not in use, a Soviet official replied, "Even satellites need a rest." It was also indicated that the next Luch launch was planned for the first part of 1988.

Before the addition of Kvant with its gyroscope at[illegible] stabilizers in 1987, orientation of Mir was effected by use of the reaction thrusters. This could explain the reference to the use of Luch being fuel-expensive.

Deputy flight director Blagov, in a paper describing Mir, provided more details. A diagram, captioned "This is how communications are implemented via the Luch relay transmitter satellite" depicts Luch as a Molniya-1 in geosynchronous orbit. Labels mark the beginning and end of the communications zone. The communications zone is labelled approximately 60 minutes and the radio shadow zone approximately 30 minutes.

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[30] Ivakhnov, A., Izvestiya, March 31, 1986, p. 3.
[31] Radio Moscow World Service in English, 0700 GMT, April 7, 1986.
[32] TASS, 1424 GMT, April 8, 1986.
[33] Radio Moscow Home Service, 1730 GMT, April 27, 1986.
[34] Flight International, October 31, 1987, p. 17.

The paper describes a unique training session using real objects and ground facilities in which the Mir station was moved out of the assembly and testing housing and its antenna aimed at the Luch satellite and all the communications modes were checked.[35]

Cosmos 1700 appeared to have failed in some respect toward the end of the summer of 1986 and began drifting off station. It was clear from the communications sessions monitored by the Kettering Group during 1987 that the cosmonauts were not using the Luch system. No lining-up routines were heard. It is possible that the geosynchronous launch failure at the end of January 1987 resulted in the loss of a replacement satellite for Cosmos 1700. No replacement appeared until November 26 when Cosmos 1897 was launched. Its initial orbital period of 1435 min was within one minute of that of Cosmos 1700 and the launch announcement included the same phrase "experimental apparatus for relaying information by telegraph and telephone" and again added that it operated in the centimeter waveband.[36] It is confidently anticipated that Cosmos 1897 will function as a data-relay satellite to support the permanent occupation of the Mir-Kvant orbital complex.

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[35] Blagov, V. D. Zemlya i Vselennaya, November-December 1986. p. 2–10.

[36] TASS, 1425 GMT, November 27, 1987.

# APPENDIX—SPACE SUPPORT SHIPS OF U.S.S.R. ACADEMY OF SCIENCES*

## ANTENNA SYSTEMS AND INDIVIDUAL FEATURES [1]

### KOSMONAUT YURIY GAGARIN

This ship was photographed passing up the English Channel on December 7, 1985, inbound Rotterdam from Nova Scotia. The *Gagarin,* callsign UKFI, is run under the auspices of the U.S.S.R. Black Sea Shipping Co. Its ice strengthened hull carries the following equipment.

On the foremast are located the ship's radars, on the port side a NATO designated "Okean," and on the starboard side, a "Don Kay" scanner; twin fog signalling devices, along with an omnidirectional VHF discone antenna, two VHF whip antennas, an MF direction finding (DF) loop, and an alt-azimuth "gunmount" platform which supports four broadband helical VHF antennas, used for Salyut and Mir communications. This quad antenna for 143 MHz work is a standard antenna on U.S.S.R. civilian tracking vessels, and is designed "Quad Ring." Aft of the foremast are located two derricks of five tonnes SWL, and a longboat.

The bridge area supports four alt-azimuth "Quad Ring" platforms, two with 143 MHz helical, and two with 922 MHz crossed Yagi antennas, another MF loop for DF work, and an omnidirectional VHF discone mounted to the port side of the bow 12 meter dish, which is used for Molniya communications work, located above the bridge. At the base of the dish is a "cherry-picker" work access platform for the 12 meter dishes, designated "Ship Bowl" and two broadband HF whips. Moving amidships, the second 12 meter dish for tracking, telemetry, and control (TTC) is located, with two cranes of 3.25 tonnes SWL, and the first 25 meter "Ship Shell" dish for deep space work, with its attendant cherrypicker. Athwarts of this dish are four quick release flotation devices, two per side, located on the outsides of the gunwale, with a spare propeller (the only vessel to carry one), and the second 25 meter "Ship Shell" dish, with platform, to the stern.

The stern itself carries the main mast, upon which is a VHF marine antenna, and two log periodic NATO designated "Vee-Cone" HF arrays, for ship to shore usage. Quite often, the Gagarin and other vessels have been picked up transmitting on marine HF frequencies, mainly to Leningrad and Odessa Radio, usually employing radio- teletype.[2] At the base of the funnel are another two VHF omnidirectional discones, and three HF whips. Four self righting, covered-in lifeboats are carried either side along the length of the ship, together with a small motor launch, with four liferaft canisters abeam of the funnel.

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*By Max White, member of the Kettering Group. The assistance of Lloyds Maritime Information Service in the compilation of this report is gratefully acknowledged.

[1] This study is the result of photographic analysis of aerial surveillance pictures taken by a UK based air-survey organization in the region of the English Channel. General descriptions, photographs of the tracking fleet, and details of NATO designations of the antennas carried can be found in the 1987-1988 edition of Jane's Fighting Ships, and construction details in Lloyd's Register of Shipping 1986-1987.

### AKADEMIK SERGEI KOROLEV

This is the most aesthetically pleasing ship of all the fleet, and is also run by the Black Sea Shipping Co. Ice strengthened, its callsign is UISZ.

The bow section carries twin derricks, the port one sporting an MF loop. Above the bridge are carried four "Quad Ring" platforms for the Salyut and Mir antennas. An indication as to how these antennas functioned was revealed in an interesting picture of the bridge area taken when the *Korolev* was heading for Rotterdam from Halifax NS on August 5, 1986, while off Cap Griz-Nez. Two of the mounts had the 143 MHz helicals "plugged in," while the other two were empty, the 922 MHz telemetry four-element Yagi's being laid on the deck; it would seem that aerials can be switched between mounts located around the ship. The length of these antennas is estimated at 2.5 meters. There is also a TV antenna located here.

The foremast carries two marine "Don Kay" radars, six VHF omnidirectional discones, and two MF loops for navigation. Surrounding the aerial mounts on the bridge are two center-loaded broadband HF whips to port, and two marine VHF whips to starboard, while toward the stern is an INMARSAT standard satellite communications dish in a small dome. This is the only ship to have such a capability. Completing this area is a small two meter dish in a dome used for TTC, designated "Ship Globe."

Amidships is a crane, and a 12 meter "Ship Bowl" dish, used for space tracking and command, on the boat deck; this dish does not appear to have a work platform. This deck appears to serve as a recreation area for the crew. The seats double up as floatable lifejacket containers, although four lifeboats nearby were in a poor shoddy condition. At the stern is the second 12 meter "Ship Bowl" dish used for Molniya relay, and the main mast, supporting a pair of HF "Vee-Cone" arrays, VHF omni-discone and whip antennas, and the foghorn. Two pairs of twin cable feed each HF log periodic. Abeam of the stern dish are 16 liferafts in groups of eight, while a solitary alt-azimuth 143 MHz helical "Quad Ring" array is located inside the taffrail.

### KOSMONAUT VLADIMIR KOMAROV

Originally known as the *Genichesk,* the *Komarov,* callsign UUVO, is run from Odessa through the same company as the *Gagarin* and *Korolev.*

Forward of the bridge on the starboard foredeck is a 143 MHz "Quad Ring" alt-azimuth mounted array, while the bridge area carries two 922 MHz 10 element Yagi arrays for Salyut and Mir telemetry, and a small omni-discone. Abeam the bridge are HF broadband whips, with additional center-loaded HF whips midships. The first TTC receiving "Ship Globe" dish of eight meter diameter, in its own 18 meter dome, is located here, along with a smaller two meter "Ship Wheel" dish in a 7.5 meter dome for tracking purposes.

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[2] Popular Communications, February 1986, p. 68.

Amidships is the main mast, carrying a set of HF "Vee-Cone" arrays, the *Komarov's* two "Don Kay" radars and MF antennas, and a VHF whip. Starboard of the mast is a large motorboat—unique to this vessel, with eight lifeboats on either gunwale. A derrick of eight tons capacity is at the foot of the main mast, which is used for launching the motorboat, and a VHF omnidirectional aerial.

Towards the stern is the second eight meter "Ship Globe" transmitting dish, and the stern mast, with the funnel incorporated. Here is the second pair of "Vee-Cone" log periodic aerials, and six lifeboats, two on the port side being of the GRP covered-in design, and one on the starboard side.

## THE BELYAYEV CLASS

*Kosmonaut Vladislav Volkov, Kosmonaut Victor Patsayev, Kosmonaut Pavel Belyayev, and Kosmonaut Georgiy Dobrovolskiy*

These vessels have been reported on numerous occasions heading in and out of the U.S.S.R. They have the callsigns UIVZ, UZYY, UTDX and UZZV respectively and are run by the U.S.S.R. Baltic Shipping Company out of Leningrad, with the exception of the *Volkov,* which is not attached to any specific fleet. All four are ice strengthened, and built at the Zhadanov yard in Leningrad.

The bow section has a derrick and foremast, upon which is an MF loop antenna, and a VHF omnidirectional discone for Salyut voice reception. From the top of the mast sloping to the prow is a center-fed dipole wire antenna. Upon the bridge are two alt-azimuth mounts for 143 MHz "Quad Ring" helicals, and a dedicated alt-azimuth mount for two right hand circular four-spiral helical antennas for telemetry work. Surrounding these arrays are a TV antenna, two HF whips, four VHF whips, and a feed cable for a long wire aerial extending from the main mast toward the stern to the mizzen mast. The mast contains the foghorn, a "Don 2" marine radar, a VHF discone, and VHF and MF direction finding arrays. Two lifeboats are either side of the bridge.

Midships is carried the main tracking antenna designated "Quad Spring," a clover leaf 4 dish alt-azimuth mounted array, with a "cherrypicker" work platform for access, stowed to the starboard side. Aside the dishes are two center-loaded whips. The funnel and surrounding deck area support a second TV antenna, two lifeboats, and three liferafts on either side, and a solitary 143 MHz "Quad Ring" array.

The mizzen mast carries a further two omnidirectional VHF discones, with an estimated 2.5 meter diameter Molniya communications dish at the base of the mast, along with twin derricks and two HF whips at the stern. As the *Kosmonaut Vladislav Volkov* was passing through the Dover Straits from Las Palmas on August 4, 1986, the deck space around the satcom dish was being used by two members of its crew for a weightlifting session.

### THE VYTEGRALES OR MORZHOVETS CLASS

*Borovichi, Kegostrov, Morzhovets, and Nevel*

These vessels make regular passages through the English Channel. They are similar to the *Belyayev* class in hull size and dimensions, but no tracking dishes are carried. Again, they are part of the Baltic Shipping Company fleet, with callsigns of UVAU, UKBH, UUYG, and UUYZ. All were built at the Zhadanov shipyard in Leningrad with the exception of the Kegostrov, constructed at the Vybord yard.

The tracking is performed through the three alt-azimuth mounts carrying 143 MHz VHF "Quad Ring" helicals, and 922 MHz Yagis, standard on all vessels, which are located on the mid-deck, with another two mounts to be found on the bridge wings. Only the mount located at the front of this deck handles voice communications, the rest being used for TTC.

The *Borovichi* is believed to have only two alt-azimuth mounts on its deck, one for 143 MHz use, and the other containing a five element helical quad array for telemetry reception; this antenna is designated "Quint Ring."

Relay of voice communications is provided by a center-fed sloping dipole in the bow, two VHF whips and three omni discones on the main mast, and two long wire HF antennas slung between the main and mizzen masts.

The bridge area has a multitude of VHF whips and two HF whips, with the funnel sporting a MF direction finding loop.

Either side of the mizzen mast is a lifeboat, and the feeds for the "Vee-Cone" periodic HF aerials, together with two pairs of HF whips and two self righting, covered-in lifeboats. The mizzen mast itself has two "Don 2" radars, the "Vee-Cone" antennas, and two VHF dipoles mounted on spreaders, with an MF open spaced wire antenna sloping from the top of the mast to the base of the funnel.

### DEPLOYMENT OF THE SOVIET TRACKING FLEET JANUARY 1981 TO SEPTEMBER 30, 1987

The eleven ships of the Soviet Academy of Sciences made a total of 87 voyages during this period, taking them to world wide locations in support of both the piloted and automated space programs. Their primary objectives were to provide communication relay links for cosmonaut activities and participation in the tracking, command and control operations required for specialized launches.

#### 1981

The main activity of 1981, the Salyut 6/Soyuz T-4/Soyuz 39/Soyuz 40 missions, required vessels in the primary areas of Gibraltar, West Africa, and South Atlantic, these being filled by the *Kosmonaut Yuriy Gagarin, Kosmonaut Vladimir Komarov, Morzhovets* and *Kegostrov* respectively. All were deployed specifically for the occupation of Salyut 6, the *Gagarin* and *Morzhovets* leaving their home ports of Odessa and Leningrad six weeks before the T-4 launch in order to be on station and settled into a daily routine. The *Kosmonaut Georgiy Dobrovolskiy* also slipped her moorings at Leningrad to proceed to the Caribbean for the whole mission, while the *Kegostrov* arrived on station off Montevideo halfway through the T–4 flight to bolster capacity in that area, and ultimately to relieve the *Morzhovets.*

After the last crew left Salyut 6, the *Komarov* and *Morzhovets* rapidly departed for the U.S.S.R., while the *Dobrovolskiy* stayed on in the Caribbean until the end of August, and the *Kogostrov* proceeding to the coast of Africa. This would be the last voyage of the *Kosmonaut Vladimir Komarov* for eleven months.

The voyage of the *Akademic Sergei Korolev* which arrived in Colombo on April 29 for a seven month deployment, before passing into the Black Sea for Odessa on November 19, apparently appeared to be unconnected with supporting piloted spaceflight. While Salyut communications could have benefited in that area, it is noticeable that the launch of the Indian Rohini 3 satellite took place only a month after the *Korolev* appeared in the vicinity: whether this was for launch support, or tracking for intelligence gathering has still to be determined, but neither the Korolev, nor any other large tracking ship, had previously been in Indo-Asian waters, or has been deployed there since.

## 1982

New Year's Day 1982 dawned upon three of the fleet at sea. The *Kosmonaut Pavel Belyayev* was in the Caribbean, the *Kosmonaut Vladislav Volkov* was completing a six month deployment off the West African coast before returning to Leningrad via Hamburg, and the *Borovichi* was drifting off the Congo. However, a rapid dispersal of six boats was noted in late March and early April prior to the launch of Salyut 7, as anchorages in the Caribbean, Gibraltar Straits and off South America were taken up. By the time of the Soyuz T–5 crew launch to Salyut 7, another two boats had been put to sea.

Initially, this was a puzzling case of overkill until June, when the *Kosmonaut Viktor Patsayev* was tracked passing out of the Suez Canal, and the *Kosmonaut Georgiy Dobrovolskiy* was reported leaving Singapore for the Suez Canal on the 15th. Obviously, these particular vessels were ignoring the Salyut mission and were concentrating on other matters—in this case, support for the first spaceplane test, Cosmos 1374, on June 3 during the terminal phase of its flight toward a landing off the Cocos Islands where another tracking ship, the *Chumikan* was located. After this unique launch, the *Dobrovolskiy* returned to Leningrad, and the *Patsayev* relocated to the Caribbean in order to relieve the *Akademik Sergei Korolev.* Another unique first was chalked up in early July, in that all eleven boats were at sea, the first and only time that this has occurred.

The *Borovichi* and *Kosmonaut Vladislav Volkov,* off Africa, were supporting retrofire for the short duration flights of Soyuz T–6 and T–7/T–5. The *Kosmonaut Vladimir Komarov,* after being substituted off Gibraltar by the *Kosmonaut Yuriy Gagarin* which came out of the Black Sea on June 2, headed into the North Atlantic to provide coverage off Ireland, interspersed with calls into Amsterdam, Hamburg, and Rotterdam, at approximately six week intervals. This first occupation of Salyut 7 continued the policy of late Salyut

6 missions of not stationing a large vessel off Sable Island NS,[3] and it is interpreted that the positioning of the *Komarov* at this time was to help fill gaps in coverage in this region. Subsequent endurance flights have since benefitted from having a vessel assigned this responsibility, for at least a good proportion of the flight, if not all.

The imminent landing of the Soyuz T-5/T-7 crew on December 10 was signalled by the return of the *Kosmonaut Vladislav Volkov* and *Kosmonaut Viktor Patsayev* to Leningrad, with the *Nevel* and *Borovichi* already bound for home. The *Komarov,* now shifted to Africa, and the *Dobrovolskiy,* two and a half months into an eight month deployment in the Caribbean, only remained on station to provide retrofire support.

## 1983

The arrival in orbit on March 29, 1983, of the Cosmos 1443 module destined for the Salyut 7 station indicated that piloted flights would soon be resuming, and with mission durations expected to increase, it would be interesting to note how the support ships would cope. Thirteen days later, the second spaceplane test was conducted, again with the landing scheduled for the Indian Ocean, and the accompanying task force as before. This time, the civilian fleet was represented by the *Kosmonaut Vladislav Volkov* in the Middle East, and the *Kosmonaut Pavel Belyayev* off Singapore. The Volkov transited the Suez Canal two weeks after the test, heading for Rotterdam and Tallinn, while the *Belyayev* steered for Montevideo and the South Atlantic to be on station when the Soyuz T-8 crew was launched to the orbiting complex on April 20.

It should be noted that the remaining spaceplane tests were conducted when Salyut 7 was unoccupied, and two boats could be released for this activity. Having the *Kosmonaut Georgiy Dobrovolskiy* and *Kosmonaut Viktor Patsayev* involved in the Cosmos 1374 flight during the Soyuz T-5/T-7 long duration flight placed a severe strain on the tracking fleet coverage.

Soyuz T-8 failed to dock, however, and had to return quickly after only a two day flight, with contingency support for such an occurrence being provided by the *Patsayev* off Africa, and by the *Komarov* recently out from Odessa, in the Mediterranean. With such an unexpected delay and no crew to track, the ships were forced to sit and wait, in the case of the *Belyayev, Kegostrov* and *Borovichi,* off South America, though the crew of the *Belyayev* relieved the monotony with a run ashore in Buenos Aires in early June.

The *Akademik Sergei Korolev* returned to Odessa later in the month from Nova Scotia, exchanging location with the outbound *Kosmonaut Yuriy Gagarin.* The boat to benefit from the hiatus was the *Kosmonaut Vladimir Komarov*—having been at sea for ten weeks in the Mediterranean, the crew was allowed to return for a week's break in Odessa before resuming normal duties back off Gibraltar just before the launch of Soyuz T-9.

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[3] U.S. Senate. Committee on Commerce, Science, and Transportation, Soviet Space Programs 1976–80, Part 1, December 1982, p. 136.

As this flight progressed, and with the expected crew rotation failing to take place following the Soyuz T–10A launch abort, Lyakhov and Aleksandrov had only Flight Control and the crews spread beneath them for company, as boats headed in and out of the U.S.S.R., until only the *Nevel* in the South Atlantic, the *Dobrovolskiy* and *Korolev* in the Caribbean, and *Morzhovets* off Dakar, were at sea to check the return of the crew. Interestingly, the responsibility for conducting the re-entry phase was assigned to the *Morzhovets;* it was unusual that a *Belyayev* class boat, or even a larger class vessel was not off Africa for this purpose. In the intervening two and a half month gap between Soyuz flights, the *Korolev, Morzhovets,* and *Dobrovolskiy* all stayed on station to overlap the completed Soyuz T–9 mission, and the upcoming Soyuz T–10 launch. All other vessels were back in the U.S.S.R. for the end of year festivities. During this time, the third spaceplane test was conducted, with the final landing point in the Black Sea. No civilian vessels were located in unusual areas on December 27, although the boats at sea could well have been involved.

## 1984

The first piloted launch of 1984, Soyuz T–10 on February 8, again produced the advance guard of the *Kegostrov* heading for South America, the *Kosmonaut Pavel Belyayev* for West Africa, and the *Kosmonaut Vladimir Komarov* passing through the Bosphorus on January 28 for the Mediterranean and its now usual residence in the Gibraltar Straits. Further departures in March from the U.S.S.R. were the *Borovichi* and *Kosmonaut Vladislav Volkov* for the Caribbean, the latter to take over from the Dobrovolskiy which called into Hamburg on March 16, inbound from Cuba, and destined for Leningrad. Three days later, the *Akademik Sergei Korolev* departed from Rotterdam in order to drift in the North Atlantic before the *Kosmonaut Yuriy Gagarin* arrived off Nova Scotia two months later. The launch of the Soyuz T–11 crew, and the flurry of EVAs that followed, required maximum coverage in April and early May, provided in the South Atlantic by the Kegostrov off Montevideo, the Mediterranean by the *Komarov,* the *Belyayev* anchored off Togo, and her sister ship, the *Patsayev* moored further north off Senegal, the Atlantic by the *Korolev,* and the *Borovichi* with the *Kosmonaut Vladislav Volkov* near St. Anna Bay in Curacao. After this phase of the mission ended, the *Gagarin* slipped out of the Black Sea headed for Cuba and then Nova Scotia, while the *Akademik Sergei Korolev* turned South for a call into the Canaries on July 10, and home to Odessa 10 days later, completing the longest deployment made by a civilian tracking ship of 11 months. It would be over a year later before the *Korolev* would put to sea.

July also saw the *Kosmonaut Pavel Belyayev* return to Leningrad and the *Kegostrov* to *Tallinn;* the *Dobrovolskiy* call into Amsterdam outbound from Leningrad and steering for Las Palmas and the Gulf of Guinea; the Komarov visit Rotterdam for four days on July 4, and then deploy into the Atlantic to cover for the *Gagarin* making her way up the Eastern Seaboard of the United States from Cuba; and the *Morzhovets* depart Leningrad for Amsterdam, and its destination for the Caribbean, and later the South Atlantic.

Among this maritime "musical chairs" came the launch of Soyuz T-12 for a 12-day flight to Salyut 7, with the boats well placed again for the spacewalk by Dzhanibekov and Savitskaya on July 25. The slowing down of activities aboard the space station for the landing of the T-10/T-11 crew in early October had begun late in September,[4] and this was reflected by the arrival of the *Kosmonaut Viktor Patsayev* back to European waters with a visit to Rotterdam, and then to Leningrad. The *Komarov* had departed into the Black Sea even earlier on August 19. For this mission, the retrofire boat was the *Kosmonaut Georgiy Dobrovolskiy,* and 12 days after the landing, the *Kosmonaut Yuriy Gagarin* docked into Rotterdam on October 14 for four days leave after crossing the Atlantic from Halifax NS. A seven month lay-up awaited the crew on their arrival in Odessa.

The end of piloted spaceflight duties brought back to port the vessels supporting the T-10/T-11 flight, and only the standing patrols of the *Dobrovolskiy* in the Caribbean, soon to be relieved by the *Belyayev,* and the South America-Equator-Africa region covered by the *Morzhovets,* were operational on November 1. With Salyut 7 flying automatically, the report that *Kosmonaut Vladimir Komarov* was negotiating the Bosphorus and steaming for the Mediterranean on the 25th raised eyebrows; no Soyuz flights were expected. Three weeks later, the first of the Vega probes to Comet Halley lifted off, to be followed on December 21 by Vega 2. This could well have been a deep space assignment, then, as the use of large class vessels for this activity is not new, and would explain the early return of the *Komarov* from Soyuz T-10/T-11 support.

Slotted between the Vega launches came the fourth spaceplane test, Cosmos 1614 launched on December 19 from Kapustin Yar, and targeted for landing in the Black Sea—conveniently flying over the *Kosmonaut Vladimir Komarov* stationed directly beneath the groundtrack. This six week voyage ended with the *Komarov* celebrating New Year afloat, and then slipping back to Odessa on January 7, 1985.

## 1985

The first four months of 1985 saw no unusual activity, with the *Belyayev* continuing its voyage in the Caribbean, the *Borovichi* substituting for the *Kegostrov* off Brazil, and the *Kosmonaut Viktor Patsayev* starting a four month shift as the African boat in March. Mid-May saw the triple departure from the U.S.S.R. of the *Nevel* and *Volkov* outbound from Leningrad, and the *Gagarin* arriving from Odessa at Las Palmas. It departed the Canaries the same time as the *Komarov* nosed past Istanbul heading for Gibraltar. Again, the "early warning" system of the dispersal of the tracking fleet indicated renewed activity in the Soyuz program, and a new launch on June 6 of the Soyuz T-13 repair crew. Further sailings in June of the *Kosmonaut Georgiy Dobrovolskiy* to Montevideo and the *Morzhovets* to the waters of the Caribbean brought groundtrack coverage up to strength, in time for the solar panel EVA conducted on August 2. During this time, the Nevel cruised from South America around southern Africa toward Mauritius, and then passed through the Suez Canal on September 16, for Leningrad. The Brazilian station was tasked to the *Kegostrov,* arriving at Recife on September 24 from Leningrad and Rotterdam.

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[4] Kidger, N. Spaceflight, March 1985, p. 134.

The partial exchange of crews aboard Salyut 7 during September 1985 and the return of the T-13 capsule, supported by the *Belyayev* off Togo, saw the same maneuvers some 300 km below. The *Kosmonaut Vladislav Volkov* called into Rotterdam inbound from the Atlantic for Leningrad; the *Dobrovolskiy* and *Belyayev* transited the same ocean in opposite directions with the *Dobrovolskiy* taking up the retrofire station off Africa for the T-14 return late in November (an indication that the problems with Vasyutin aboard Salyut 7 were well known), and then to Leningrad, while the *Kosmonaut Pavel Belyayev* arrived off Uruguay. The deployment of the *Patsayev* at this time, reported passing through the Kiel Canal on November 10 for Curacao, seemed odd since coverage for geostationary injection firings monitored by vessels in the Equatorial region of the Atlantic was adequately provided by the *Kegostrov* and *Borovichi* into December, augmented by the *Belyayev* for two months. However, with Western observers concentrating on the crew activities, the Atlantic exchange of the *Kosmonaut Yuriy Gagarin* and *Kosmonaut Vladimir Komarov* failed to attract attention—in its own way, a significant step, in that the *Gagarin* was returned across the Atlantic to the Canary Islands. It had been at sea 115 days, and with onboard reserves capable of carrying 130 days worth of supplies for ocean going duty, a refueling call was required. It may be asked why Halifax NS was not selected as a suitable port of call, but it is known that the Soviet merchant marines do have a refuelling contract at Las Palmas.[5] To cover the North Atlantic region, the Gibraltar slot of the *Komarov* was forsaken for a two day call into Rotterdam on August 19 and a departure for off Ireland, before returning to Odessa after 145 days at sea. The *Gagarin* returned to Canada, and one week later on October 19, the *Akademik Sergei Korolev* arrived in Greece from the Black Sea after a 15 month refit. It left Patras after two days, setting course for Gibraltar and an expected long duration duty—except it re-entered the Black Sea only five days after the return of the Soyuz T-13/T-14 crew, to be followed three weeks later by the *Gagarin.* The close of 1985, which should have had a crew in space, left four boats spaced between the Caribbean and Argentina waiting for their next mission, and the crew of the *Akademik Sergei Korolev* enjoying an unexpected shore leave.

## 1986

January 25, 1986, saw the *Korolev* retracing its steps through the Bosphorus, destined for the coastline of Nova Scotia, shadowed two weeks later by the *Komarov* for a shorter trip to the Mediterranean. Coincident with the launch of the new Mir space station on February 20 were the departures of the *Volkov* and *Nevel* from Leningrad, destined for Africa and South America, and the landfalls of the *Kegostrov* and *Patsayev* to the same port. With the launch of the Soyuz T-15 crew, tracking ship activity concentrated on covering the standard areas: the *Volkov* off Lome for the complete mission, assisted by the *Kegostrov* for retrofire; the *Dobrovolskiy* and *Nevel* in the South Atlantic region for the whole flight, with the *Morzhovets* entrusted with the Caribbean. The homecoming of the *Kosmonaut Vladimir Komarov* to the Black Sea on June 10 necessitated a short cruise by the *Kosmonaut Yuriy Gagarin* to support the transfer of the T-15 crew from Salyut 7 back to Mir on June 26. This two week run is the shortest ever yet undertaken for support requirements, although it also served a dual purpose as a shakedown passage after six months away from sea.

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[5] White, M. Locations of the Soviet Tracking Ships. May-Aug. 1987, Kettering Group Tech Memo MW8705, September 1987.

With the return of the Soyuz T-15 crew in July, maritime activity quieted to a minimum. The *Kosmonaut Viktor Patsayev* embarked on a posting to the South Atlantic in the company of the *Borovichi* and both were on station at the end of the year. The Caribbean slot was relinquished by the *Morzhovets* in mid-August, and handed to the *Kosmonaut Pavel Belyayev* until it returned to Tallinn in late November. The intervening time off from seaborne operations enabled the fleet to prepare for the next occupation of Mir.

### 1987

After six months grace, the impending occupation of Mir was announced by the Soviets on January 28, 1987. To observers with their attention on the Bosphorus, the news was three weeks late, as the familiar and unmistakable outline of the *Kosmonaut Yuriy Gagarin* left Odessa, called into Las Palmas for three days on January 21, and set sail for Sable Island NS. January 27 saw the appearance of the *Komarov,* headed for the Straits of Gibraltar and a four month stay in the Mediterranean, with visits to Tangier, Marseilles, and Ceuta. The *Patsayev* had shifted across the Atlantic in the meantime to act as Africa retrofire boat, in case of an unsuccessful docking by the Soyuz TM-2 crew launched on February 5, while the *Nevel* and *Volkov* waited off Brazil. The *Borovichi* continued off Uruguay. With Romanenko and Laveikin settled aboard Mir, the *Kosmonaut Viktor Patsayev* departed the scene after calling into the Canaries for Tallinn. The *Kegostrov* arrived from Leningrad at Copenhagen, departing April 21 for the Gulf of Mexico.

The *Belyayev* departed Rotterdam outbound on April 27. Initially this was thought to be destined for Africa, which was not covered, and confidence increased when Las Palmas reported its arrival on June 2 for two days. Two weeks later, the name *Kosmonaut Pavel Belyayev* appeared in the list of vessels having transited the Suez Canal, heading south for an undisclosed location, possibly for a position off East Africa in order to track the orbital insertion phase of sun-synchronous launch. The Soviet launch of the Indian remote sensing satellite, IRS 1, had been announced for August or September. Its arrival into Aden on July 1 strengthened this theory, and on August 1, a 97 degree polar launch occurred—but of Cosmos 1871, and not IRS. Immediately dubbed a new style photo reconnaissance flight by some Western analysts, it seems hard to believe that a tracking vessel would be sent to such a specific location unless the launch were something unusual. Soon after, the *Belyayev* returned into the Mediterranean, with the Indian launch still awaited and leaving the distinct impression that it had been supporting a launch vehicle test. As of September 30, it was situated off Guinea.[6]

The Nova Scotia position was vacated by the *Gagarin* in May, after a 125 day voyage only interrupted by a two-call into Sydney NS on March 5. Again, as two years previously, a refueling trip was arranged for Las Palmas with approximately five days supply of fuel left on board. No coverage was performed in the North Atlantic by any other vessels at this time. The *Gagarin* subsequently departed back for Canada on May 29.

The week-long trip of the Syrian crew to Mir between July 22–30 again required re-entry assistance, and the *Kosmonaut Vladimir Komarov* relocated from Gibraltar to Africa, via a stop in the Canaries, to perform this task. Only a call in Greece awaited the crew before the *Komarov* returned to the Black Sea on August 14.

With the duration of the TM–2/TM–3 crew setting new space records, the tracking fleet also had to pace itself. The *Kosmonaut Yuriy Gagarin* eventually headed through Istanbul on August 31 after over 150 days on duty. By this time, the *Akademik Sergei Korolev* had been settled on station for a month in the region of Sable Island after an 11-month refit in Odessa. As of September 30, it was drifting off Sydney NS after a two day call there a week earlier. The same date saw the *Nevel* less than a month out of Leningrad destined as the Caribbean vessel, with the *Borovichi* on station off Buenos Aires. The *Kegostrov* was inbound for Tallinn after six months in the Lesser Antilles, both the *Kosmonaut Georgiy Dobrovolskiy* and *Kosmonaut Pavel Belyayev* were completing tours off Africa—in the case of the *Dobrovolskiy* over eight months at sea, and the *Kosmonaut Viktor Patsayev* was outbound from Leningrad. This produced yet another first in the tracking fleet program, with it taking up position in the Mediterranean. Never before had this been done by a *Belyayev* class boat in place of a larger vessel, showing still the necessity of seaborne tracking stations on a daily basis, and the flexibility of the Soviet fleet.

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[6] White, M., Kettering Group Tech Memo MW8706, November 1987.

TABLE 34.—SOVIET CIVILIAN SPACE TRACKING FLEET DISPERSAL DURING PILOTED SPACEFLIGHT MISSIONS, 1981–1987 [1]

| Mission | Nova Scotia | Atlantic | Gibraltar | West Africa | South Atlantic | Caribbean | Mediterranean |
|---|---|---|---|---|---|---|---|
| 1981 | | | | | | | |
| Salyut 6/T–4/ Soyuz 39/40 | | | Gagarin | Komarov | Kegostrov<br>Morzhovets | Dobrovolsky | |
| 1982 | | | | | | | |
| Salyut 6/T–5/T–6/T–7 | | Komarov | Komarov<br>Gagarin | Gagarin<br>Volkov<br>Borovichi | Morzhovets<br>Nevel<br>Borovichi | Korolev<br>Patsayev<br>Dobrovolsky | Komarov |
| 1983 | | | | | | | |
| Salyut 7/T–8/T–9 | Korolev<br>Gagarin | | Komarov | Patsayev<br>Morzhovets<br>Kegostrov | Belyayev<br>Nevel<br>Borovichi | Korolev<br>Patsayev<br>Dobrovolsky | |
| 1984 | | | | | | | |
| Salyut 7/T–10/T–11/T–12 | Gagarin | Korolev | Komarov | Volkov<br>Patsayev<br>Dobrovolsky<br>Belyayev<br>Morzhovets | Volkov<br>Nevel<br>Kegostrov | Korolev<br>Volkov<br>Patsayev<br>Borovichi | |
| 1985 | | | | | | | |
| Salyut 7/T–13/T–14 | Gagarin | Komarov | Komarov | Patsayev<br>Belyayev | Volkov<br>Dobrovolsky<br>Nevel<br>Borovichi<br>Kegostrov | Morzhovets | |
| 1986 | | | | | | | |
| Mir/Salyut 7/T–15 | Korolev | | Komarov | Volkov<br>Kegostrov | Dobrovolsky<br>Nevel | Morzhovets | Gagarin |
| 1987 | | | | | | | |
| Mir/TM–2/TM–3 (to Sept. 30 1987) | Gagarin<br>Korolev | Gagarin | Komarov | Komarov<br>Patsayev<br>Dobrovolsky<br>Belyayev | Volkov<br>Dobrovolsky<br>Borovichi<br>Morzhovets | Nevel | Patsayev |

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[1] Prepared for the Congressional Research Service by Max White.